This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

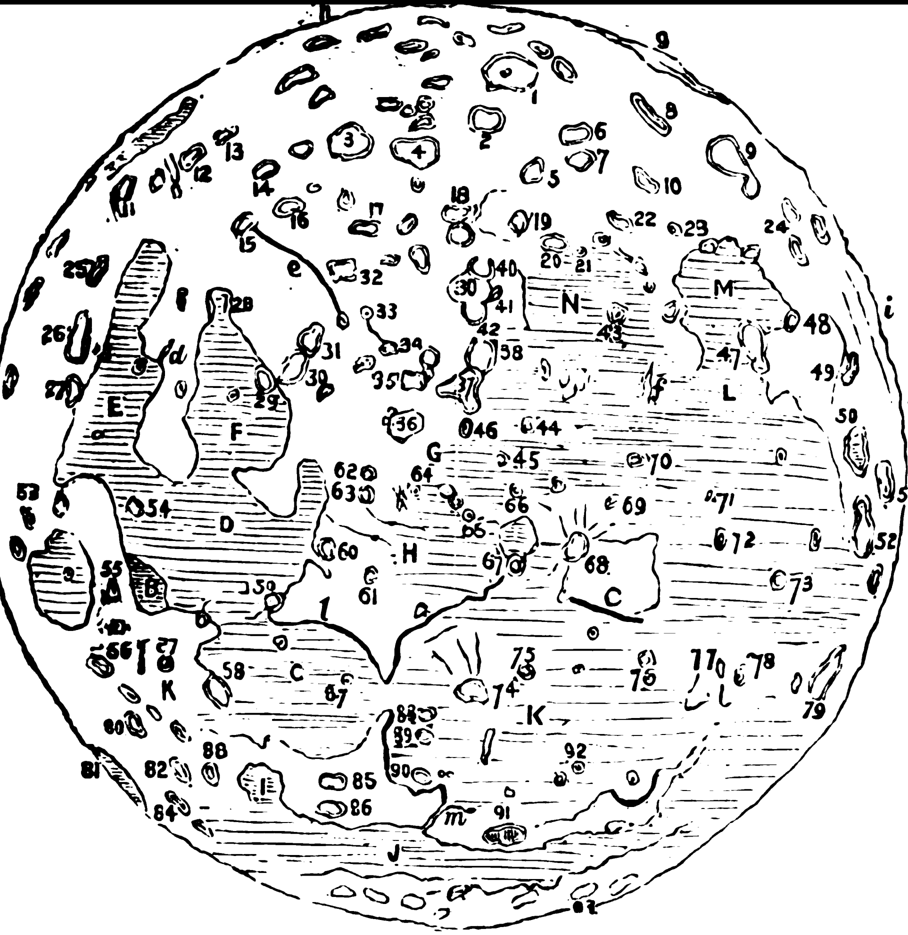
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



Astronomy

Edmund Neison

KD49814

ASTRONOMY.

New Educational Works.

ENGLISH GRAMMAR:

A Manual of the English Grammar and Language, for Self-Help.

By L. TOULMIN SMITH.

Price One Shilling.

FRENCH GRAMMAR:

Lessons in French Grammar and Pronunciation, for Self-Educators.

By JULES A. L. KUNZ.

Price Two Shillings.

(*Key to the above, price* 1*s.* 6*d.*)

WARD, LOCK, AND CO., LONDON AND NEW YORK.

ASTRONOMY:

A SIMPLE INTRODUCTION TO A NOBLE SCIENCE.

BY

EDMUND NEISON, F.R.A.S.,

Her Majesty's Astronomer for Natal.

WARD, LOCK, AND CO.
LONDON: WARWICK HOUSE, SALISBURY SQUARE, E.C.
NEW YORK: BOND STREET
1886.

[*All rights reserved.*

KD 49814

HARVARD
UNIVERSITY
LIBRARY
JUN 5 1953

52 457

PREFACE.

THE present little work was undertaken in the years 1880—1882, as a series of popularly written articles for the pages of the UNIVERSAL INSTRUCTOR, with the view of their serving as an introduction to Astronomy for those who had no previous knowledge of the science.

The work is divided into two parts—the first to form a sort of historical introduction, and the second to constitute a more systematic description. From the earlier pages there can be learnt those elementary data, and the meaning of those technical terms, which are necessary for the proper comprehension of the more systematic account of Astronomy forming the second part of the little work.

Many of the illustrations in the first portion of the work are taken from woodcuts in the earlier contributions to our knowledge of Astronomy. But, throughout, no attempt at refinement has been made in the illustrations, as the soft aspect and delicate gradations of light and shade inseparable from the proper delineation of the planets, comets, and nebulæ, can rarely be reproduced by ordinary woodcuts; whilst for the present purpose any other process was out of the question. The figures are sufficient, however, for the only purpose desired,—the elucidation of the descriptive text.

Since its appearance in the pages of the UNIVERSAL INSTRUCTOR, the work has been revised and practically brought up to date; and it is hoped that by enlisting further recruits to our ranks, it may tend to the advance of Astronomy. E. N.

August, 1886.

CONTENTS.

PART I.

CHAPTER PAGE
I. INTRODUCTORY: IN THE BEGINNING OF THE SEVENTEENTH CENTURY 1
II. EARLY CONTRIBUTIONS TO ASTRONOMY 18
III. IMPROVED ASTRONOMICAL INSTRUMENTS 36
IV. FURTHER TELESCOPIC DISCOVERIES 45
V. NEWTON'S CONTRIBUTIONS 55
VI. FOUNDATION OF SYSTEMATIC OBSERVATIONS . . . 62
VII. MODERN MATHEMATICAL ASTRONOMY 70
VIII. NEW TELESCOPES AND DISCOVERIES 73
IX. THE MINOR PLANETS 81
X. MODERN DISCOVERIES 87

PART II.

XI. THE SOLAR SYSTEM 107
XII. THE SUN 117
XIII. INTRA-MERCURIAL PLANETS 127
XIV. MERCURY AND VENUS 129
XV. THE EARTH AND THE MOON 133
XVI. MARS AND THE MINOR PLANETS 146
XVII. JUPITER AND SATURN 150
XVIII. URANUS, NEPTUNE, AND ULTRA-NEPTUNIAN PLANETS 156
XIX. COMETS AND METEORS 159
XX. ULTRA-SOLARIAN ASTRONOMY 168
XXI. DOUBLE STARS 171
XXII. VARIABLE AND TEMPORARY STARS 177
XXIII. THE STARS AS SUNS 179
XXIV. THE NEBULÆ 188
XXV. THE TELESCOPE 191
XXVI. WORK FOR THE TELESCOPE 202

ASTRONOMY.

CHAPTER I.

INTRODUCTORY: IN THE BEGINNING OF THE SEVENTEENTH CENTURY.

The origin of Astronomy—Aim of the present work—The Historical method—Astronomy at the end of the sixteenth century—The Apparent Motion of the Heavens—Different lengths of days—Celestial Equator—The Ecliptic—The Solar day—The Sidereal day—Rising and Setting of celestial bodies—Motion of the Moon—An objection to the Copernican Theory—The Months—Eclipse of the Sun—Motion of the Lunar Nodes—Phases of the Moon—Solar Eclipses—Distance of the Moon—Parallax—Apparent diameter and real size of the Moon—Lunar Eclipses—The Planets—Distance of the Planets—Their position and motion—Inferior Planets—The Constellations—Celestial Longitude and Latitude.

ASTRONOMY, probably the most ancient of the physical sciences, has maintained itself from the earliest known periods as one of the grandest branches of learning—a study worthy of the closest attention of the wisest monarchs and the assiduous devotion of the most eminent sages.

Astronomy originated in astrology.

For ages it was believed that hidden in the ever-varying aspect of the heavens was the key to the future destinies of the world and its multitudinous inhabitants. To him who deciphered that key, everything would stand revealed, and he would be master of the secrets of nature. Knowledge is power, and he who was master of the future could rule the world. This was felt to be a glorious ambition, and an end worthy of the devotion of a lifetime, so that the greatest philosophers turned their attention to the assiduous study of the science which held out the hope of such a vast return. Other sciences, and especially geometry, were devised, learnt, and extended, but in most cases merely as an auxiliary by means of which astronomy could be still better understood. In those days astronomy and astrology were convertible terms.

As science progressed it slowly began to be understood that this hope was vain, and that the heavens were not merely pictures of the future of man. But by this time astronomy had received a firm foundation, its fascinating interest as a science had begun to make itself felt. With a sigh the votaries of philosophy slowly gave up their astrological dreams and commenced to study astronomy as a science. They devoted their energies to determining its laws and ascertaining the real meaning of its wonderful phenomena. Modern astronomy commenced, and the science made giant strides in the path of progress. Brilliant discoveries rewarded the intellectual labour bestowed on the science, and slowly but surely was reared the magnificent edifice of modern theoretical and physical astronomy.

Aim of the present account of astronomy.

In the present pages it is proposed to give a short account of astronomy—an account which is to be sufficiently extensive to enable any one to gain a clear idea of the results which have been already achieved by the study of this noble science, without its being essential that he should possess any previous knowledge of its technicalities. It is not our aim to teach astronomy, for that would require a thousand of these pages. Nor do we propose to write an introduction to astronomy as a science, for that would be out of place. Lastly, it is not our intention to write a treatise on astronomy, for to this both objections would apply. We mean to give, as already stated, a short account of astronomy, and to make it as interesting and valuable as we can. A popular account it needs must be, an accurate account it is to be, and an instructive account it ought to be. At the same time care will be taken that he who proposes to devote an especial attention to astronomy, whose proud ambition it is to become an astronomer, will find in these pages a substantial basis on which to prosecute those further studies without which he can never realize his aim. Nor will the owner of an astronomical telescope, that most delightful instrument, find that his interests have been forgotten. If he finds much about what has been seen or has been discovered, he will also find something about what waits to be discovered or remains to be seen, and he may learn how to utilize his telescope to the best end, and perchance how to enrol his name in the glorious list of those who have advanced astronomy by their discoveries. But it is time to stop, lest by misadventure more is promised than is carried out.

Modern astronomy may be said to commence with the seventeenth century, when the indefatigable Kepler laid the foundation for the grand achievements of mathematical astronomy by the discovery of his famous three laws, and the illustrious Galileo Galilei inaugurated the wondrous discoveries of physical astronomy by constructing the first astronomical telescope and turning it on the heavens. We are going to describe modern astronomy, and it is here that we should begin.

It is true that during the century previous to this epoch the study of astronomy had engaged the attention of many great philosophers, and that during its later years that most celebrated astronomer Tycho Brahé had accumulated a most precious store of observations. Yet it was only during the seventeenth century that these observations were properly reduced and rendered subservient to the progress of modern astronomy. It is also true that many most important astronomical facts had been discovered by the zealous labours of the famous astronomers of the ancients; but these belong to the astronomy of their own period, and in general were not properly understood until after the commencement of the seventeenth century. It is therefore with the seventeenth century that our modern astronomy begins, and it is with that period that we shall commence.

Much has been written, and more has been said, by different

Historical method best for studying astronomy.

philosophers on the best method of introducing a science like astronomy. For our present purpose the most satisfactory way would appear to be to commence *de novo*, and retrace the path by which astronomy has reached its present grandeur. We thus proceed step by step in the same manner as the science has itself progressed; we arrive at the same difficulties, and overcome them in the same order, as these difficulties presented themselves to and were overcome by those illustrious astronomers who have rendered the science what it is at present. Each problem will then come before us in the most natural way, and we shall not raise unnecessary difficulties by discussing the minutiæ of the science before we have understood the broad principles. An historical account of the progress of astronomy, it would also appear, ought to be the most interesting method of stating the achievements of the science, and this is no slight matter. We shall then find ourselves placed in the same position as those famous men of genius who have had to face the difficulties of the science, and have triumphantly overcome them. We shall be able to understand their difficulties, sympathize with them in their perplexities and rejoice in their triumphs, whilst we shall see how each success has widened the science of astronomy, dissipated its difficulties, and led to fresh and as brilliant discoveries. By all means, therefore, let us proceed by giving an historical account of the progress and achievements of astronomy.

In this historical account it is not intended to maintain chronological order with great strictness, for that would be inconvenient at times. Liberty must be reserved to pursue the history of each branch of our subject by itself, if that should seem advantageous. And when an anachronism is committed, perchance for the sake of clearness, or even an error by some mischance, forgiveness is now craved at the very beginning.

Imagine ourselves back in the beginning of the seventeenth century, with all our trials and triumphs before us. What amount of astronomical knowledge could we learn from the labours of our predecessors?

Astronomical knowledge at end of 16th century.

From that famous work *De Revolutionibus Orbium Celestium*, of the great canon of Thorn, Nicolas Copernicus, we should be able to learn the main point of the ~~true~~ system of the universe. We should know that the sun was placed at the centre of the solar system, and that the earth and other planets were much smaller bodies moving round the sun. We should recognise that the moon was a satellite of the earth, moving round it and accompanying it in its annual journey round the sun. We should also be aware that the earth rotated on its axis in about twenty-four hours, and that this axis was inclined to the plane of the orbit of the earth.

Explanation of apparent motion of the heavens.

Let us see how far this knowledge would enable us to explain the phenomena of the heavens. And for this purpose let us sally out to our observatory, situated in the country village of Hampstead. The apparent motion of the heavens from east to west would not stop us for a moment. Every one knows that the sun, moon and stars rise every day in the east and set in the west; and it is apparent that this is at once explained by the daily rotation of the earth on its axis in an opposite direction—that is, from west to east. Nor should we require to go to an observatory to learn that the sun is higher in the heavens in summer than in winter. This we should soon see was the result of the inclination of the axis of the earth to the plane of its orbit. Fig. 1 shows this at once. We see the earth drawn as it is placed with regard to the sun at different times in the year. P is the north pole of the earth, and the straight line apparently dividing the earth into two halves is the equator, or great circle round the earth. In March it will be seen that the sun is overhead at the equator, and in England is about 51° from the zenith or point exactly overhead when it is in the meridian or great circle passing through the poles of the earth and zenith of the observer. As the earth moves in its orbit, the sun seems to rise higher in the heavens, until in June it is overhead in the circle round the earth which is shown to the north of the equator, or nearer the pole P. It is then in England only about 28° from the zenith when in the meridian. It is now summer in the northern hemisphere but winter in the southern hemisphere, for the figure will show that when elevated in the northern hemisphere it must be depressed in the southern. As the earth proceeds in its annual journey the sun gets gradually lower in the heavens, until in September it is again overhead at the equator, or in exactly the same position as in March. Finally, still falling in elevation, in December it is overhead in the places on the circle to the south of the equator, and in England when

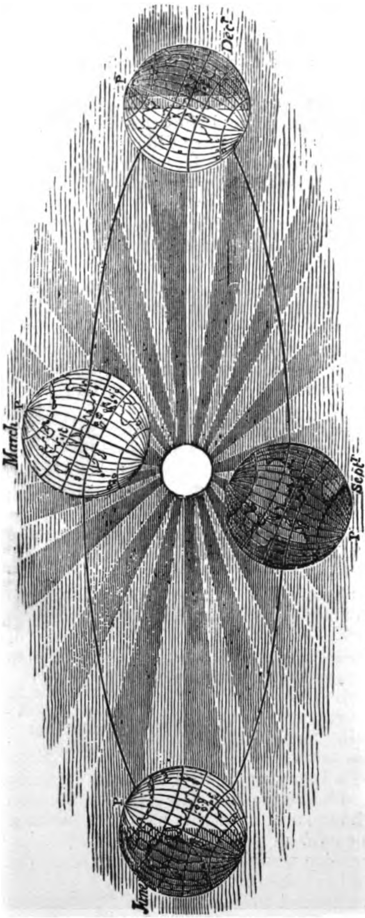


FIG 1.—THE EARTH IN RELATION TO THE SUN.

on the meridian rises only about 16° above the horizon. It is now winter in the northern hemisphere and summer in the southern.

Origin of the different length of the days.

Further inspection of the figure will show how the difference in the length of the days and nights will be accounted for. The shaded portion of the globe shows the portion in which it is night, and the remainder that in which it is day. In March the entire visible portion, or exactly one-half of both southern and northern hemispheres, is illuminated, so that in every part of the globe there is twelve hours in the illuminated portion and twelve hours in the dark portion. In March, or our spring, therefore, the day and night are twelve hours long. In June, however, it will be seen that more than one-half of the northern hemisphere is illuminated, and less than one-half of the southern hemisphere; consequently a point in the northern hemisphere will be for more than twelve hours in the bright portion and for less than twelve in the dark portion, so that the days will be long and the nights short. In fact, near the pole it will be seen that the entire circumference is illuminated, so that the sun will be always visible and there will be no night. In the southern hemisphere it will be seen that the nights are long and days short, and near the south pole there is perpetual night. It will be seen that only at the equator are the day and night always of equal length.

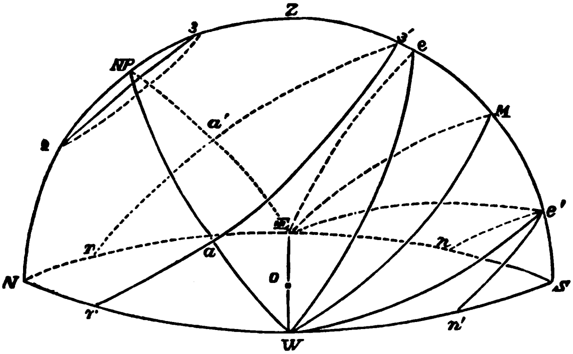


FIG. 2.—A PLAN OF THE HEAVENS.

Celestial equator.

Let Fig. 2 represent a kind of plan of the heavens as seen from our imaginary observatory, O. The horizon will be represented by the circle N W S E, where the letters stand at the north, west, south, and east points. The meridian will be denoted by the semicircle N NP Z S, where NP shows the place of the north pole and Z of the zenith or point exactly overhead of O. The equator, or rather the celestial equator, which is supposed to be the great circle in which the plane of the equator may be imagined to intersect the heavens, is represented by W M E, it always passing through the east and west points of the horizon. All these points will remain invariably in the same place in the celestial hemisphere as seen from our observatory.

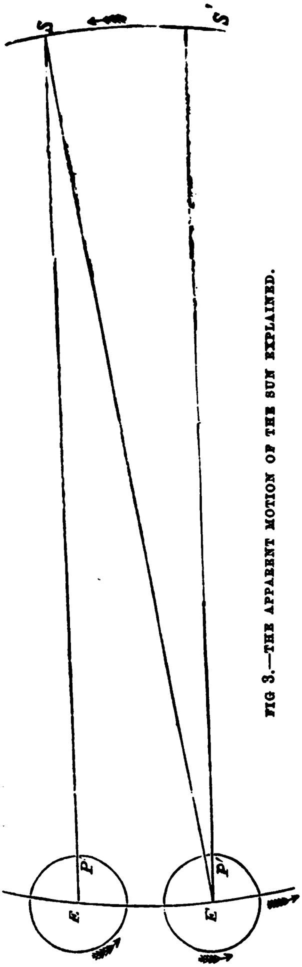


FIG 3.—THE APPARENT MOTION OF THE SUN EXPLAINED.

Ecliptic.

Suppose it is noon on the longest day in the year, which is in June, then W *e* E will show the position of the ecliptic in the heavens, and the sun will be at *e* on the meridian, at its highest point above the horizon; then the angle between the ecliptic, E *e* W, and the equator, E M W, will be equal to the distance *e* M, or the sun will be elevated as much above the equator as the ecliptic is inclined to the equator. Suppose we wait six months, until noon on the shortest day in the year, which will be in December; then the position of the ecliptic will be shown by W *e′* E, or the sun will be depressed as much below the equator as before it was elevated above. Now let us measure in June and December the height of the sun at noon; then the difference between these two heights will be equal to the distance *e e′*, or twice the angle between the ecliptic and the equator. Now, in 1600 this had been already carefully done by Tycho Brahé (in 1581), who found that the angle between the equator and ecliptic was equal to 23° 29′ 5″: a little smaller than it had been found to be by Waltherius, a German astronomer, who in 1490 found it to be 23° 29′ 47″. We now know that it is really slowly decreasing, by about 48·9″ per century, and its present value is only 23° 27′ 18″. This angle is called the *obliquity of the ecliptic*, and is of course equal to the angle made by the earth's axis with the perpendicular to the earth's orbit.

Obliquity of ecliptic.

The ecliptic or apparent path of the sun in the heavens can be easily laid down by watching the motion of the sun amongst the stars. Suppose we watch the stars which are seen near the sun at sunset and at sunrise: it will soon be seen that the stars seen at sunrise, and there-

Position of the ecliptic in the heavens.

we !!

Apparent motion of the sun. Solar day.

Apparent motion of the stars. Sidereal day.

fore to the west of the sun, gradually increase their distance from that luminary, and rise earlier and earlier before the sun, whilst the stars seen at sunset, and therefore to the east of the sun, seem gradually to approach the sun until they are so close that they can no longer be seen at sunset. It is evident, therefore, that the sun seems to move towards the ~~east~~, for the stars, we know, are to all intents fixed in the heavens. This apparent motion of the sun we should easily find was rather less than a degree per day, but to vary slightly, so that on some days it moves about 62′, and on others only 57′. It moves fastest in December, and slowest in June. This apparent motion of the sun is of course seen to be explained by the motion of the earth in its orbit, as is shown by Fig. 3. Here E E′ may be considered to represent the different positions of the earth in its orbit on two successive days, the arrows showing the direction of the motion of the earth in its orbit, and its rotation on its axis. During the time it takes the earth to make one complete revolution on its axis, the earth has moved in its orbit from E to E′. The sun, therefore, no longer appears in the direction E S, or E′ S′, which is parallel to it, but appears to have moved towards the east, and to be in the direction E′ S. The earth has therefore to rotate still more on its axis before the point P comes in the straight line between the sun and centre of the earth. Now, the average interval between the point P coming successively between the earth's centre and the sun is what is called a mean solar day, and is taken to be twenty-four hours, and this we have seen is rather more than the time occupied by the earth rotating on its axis. A mean solar day is longer than one complete rotation of the earth on its axis by just the average time it takes the earth in its rotation to overtake the sun in its apparent motion amongst the stars. In one year of 365¼ solar days the sun seems to move right round the heavens, or 360 degrees, so that in one day it will seem to move 1 ÷ 365¼ part of these 360 degrees, or 58′ 11¼″. In one solar day, or 24 hours, the earth rotates on its axis just these 360 degrees *plus* this extra 365¼ part of a rotation necessary to overtake the sun again. To find out the time in which the earth makes one complete rotation is therefore merely a sum in proportion of the form as $1+\frac{1}{365\frac{1}{4}}$ is to 24 hours, so is 1 to a complete rotation of the earth, or 23 hours 56 minutes 4 seconds. The earth, therefore, in one year of 365¼ days, rotates on its axis exactly 366¼ times. As the stars are very far off, they do not appear to alter their direction as the earth moves in its orbit, and come back to the meridian after one complete rotation of the earth. This period is called a sidereal day, and we see it is 3 minutes 56 seconds shorter than a solar day. The stars, therefore, which appear due south at ten o'clock on one day will seem to be due south at 9 hours 56 minutes 4 seconds on the next day, or 3 minutes 56 seconds earlier, and a month later will seem to be due south at eight o'clock. Accordingly, as the year goes on the aspect of the evening skies continually alters, stars which were high up in the east on a June evening will be low down in the west at the same hour on a

September evening, but by the same day of the next year the heavens have come back to their pristine appearance. All these facts were perfectly well known at the beginning of the seventeenth century.

Rising and setting of celestial bodies.

From the rotation of the earth on its axis, every heavenly body appears to rise from the east and sink to the west, moving apparently in a path parallel with the celestial equator. At any time we always see half the celestial equator, so that stars near it remain for some twelve hours above the horizon. If the star is a good deal to the north of the equator, in the northern hemisphere it remains more than twelve hours above the horizon. Thus in our imaginary observatory T 3′ *r* shows the path of a star about 30° above the equator. The great circle E NP W, perpendicular to the equator, divides the daily or diurnal apparent path of a body into two halves, each of which it requires about twelve hours to traverse. It will be seen that those stars which are more than 40° from the equator will never set at all at our observatory, but move in circles round and round the pole NP. The path of a star about 70° from the equator is shown at 2, 3, in the figure. A star south of the equator will seem to be above the horizon for far less than twelve hours, for exactly the reverse reason; and stars near the south pole will never be seen at all from our supposititious observatory. In the figure *n e′ n′* shows the apparent path of the sun on the shortest day in December, when it is above the horizon for only 7½ hours, whilst on the longest day in June it is above the horizon for 17 hours.

We have already devoted some attention to the study of the apparent motion of the sun in the heavens: let us now study the real motion of the moon—the attendant on the earth in its annual journey round the sun.

Motion of the moon.

From a very early period much attention had been devoted to the study of the motion of the moon, for it was justly regarded as being to the earth only second in importance to the sun. Its proximity to the earth, its apparent size, its utility to us terrestial inhabitants, all pointed it out as a body to be most assiduously studied. It was, moreover, the only known satellite—a fact increasing the interest belonging to this unique body.

The moon as an objection to the Copernican Theory.

Many celebrated philosophers urged that, as the earth was the sole member of the family of planets of the solar system which was dignified by possessing a satellite, this could only be on account of the earth possessing some particular importance in the solar system. Here, then, they said, is a grave objection to this theory advocated by that dreamer Copernicus and that mad theorist Kepler, for it does not assign to the earth any particular dignity of place or importance in function. On this theory, they urged, is it not Mercury, important from its proximity to the sun, or still more likely, Saturn, the planet which is farthest from the sun, and therefore that receiving the least light,—is it not one of these which is of most importance, and should be dignified by the possession of a moon? If this comparatively insignificant earth possess one satellite, why, Mars should have two, Jupiter should have four, and Saturn eight moons, which is absurd. There must be something imperfect in this theory of Copernicus, or it would not leave without explanation such an important point as the unique satellite being appended to the earth. And in those days much gravity was attached to reasoning of this character.

Sidereal and synodical months.

The motion of the moon in the heavens is far more easily studied than that of the sun, because, even when the moon is at its brightest, the more important stars can be seen when quite close to it. It was easy, therefore, for the earlier astronomers to find out the path of the moon in the skies. It was soon found that the moon performed its revolution round the earth from west to east in the same direction as the sun, and on an average once in 27 days 7 hours 43 minutes; for in the course of that time it again returned to the same place amongst the stars. This period is called a mean sidereal month. It takes the moon a longer period to come back to the same position with regard to the sun, because during these 27⅓ days the sun has itself moved a considerable distance towards the east, and the moon has to move a correspondingly increased distance before it overtakes the sun again. It requires, in fact, on the average, a period of 29 days 12 hours 44 minutes, and this is called a lunar month or synodical revolution of the moon—it being the interval between two successive new moons.

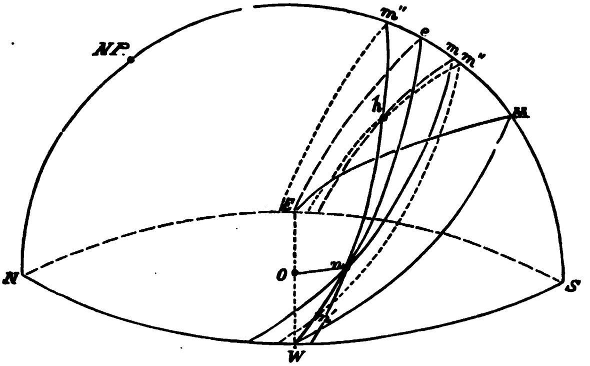


FIG. 4.—A PLAN OF THE HEAVENS.

We have seen, however, that the sun does not move always at the same rate; so that when it is moving fastest, which is in December, the moon will have to move farther to overtake it, and will require a longer period to do so than in June, when the sun is moving slowest. For this reason, during the winter the lunar months are, on the average, eight hours longer than in the summer.

At a very early period it was noticed that the moon did not move in the heavens in the same path as the sun; for it is evident that if it did, when it overtook and passed the sun, as it does at every new moon, it would come between the earth and the sun,—in fact, it would seem to pass in front of the sun, and would hide that luminary from us. This would produce what is called an eclipse of the sun.

Eclipse of the sun.

But astronomers knew that the sun was not eclipsed every month, so that it was evident that the moon, when it overtook the sun, must pass either above it or below it, or perhaps sometimes one and sometimes the other. The path of the sun amongst the stars, or the ecliptic as it is called, being known, by watching the motion of the moon it was soon seen that the moon moved in a path making a small angle with the ecliptic. Hipparchus, a celebrated Grecian astronomer, who lived at Alexandria between B.C. 190 and B.C. 120, very carefully measured this inclination of the path of the moon to the ecliptic, and found it to be equal to $5^\circ\ 0'$—a value very near the truth, which is $5^\circ\ 8'\ 40''$.

In fig. 4 there is a plan of the heavens, like fig. 3, and the path of the moon is represented by $n\ m\ h$ inclined at a small angle to W e E, the path of the sun, or ecliptic. The place n, where the two paths intersect each other, is called the *node;* and n is called the *descending node* when, as in the figure, it is the node where the moon descends from the half of its path which is above or north of the ecliptic to the half which is south or below the ecliptic. For the same reason, the other node, which is exactly opposite in the other half of the heavens, is called the *ascending node*, for it is the place where the moon seems to ascend from the southern half of its path into the northern half. The line connecting these two nodes is called the *line of nodes*, and half is shown by $n\ o$. The position of the moon's orbit when n is the *ascending node* is shown by $n\ m''$.

Motion of the nodes.

Observations soon showed that the moon's path was not invariably fixed, like the path of the sun, but that it seemed to move slowly amongst the stars. Suppose we observe the moon cross the ecliptic quite close to the bright star called *Regulus:* about twenty-seven days later we shall again see the moon crossing the ecliptic, but now it will be about a degree and a half, or three times the apparent diameter of the moon, farther west, and on the next occasion it will be the same amount still farther west. The place where the moon crosses the ecliptic moves farther west every lunation, until, in process of time, it moves right round the ecliptic. Hipparchus, who was the first to exactly measure the inclination of the path of the moon, carefully determined the time it took the node to move round the ecliptic, and found that it did so once in 18⅔ years, which is very nearly correct.

The well-known phases of the moon admitted of an easy explanation, as shown by fig. 5, so that at an early period it was known that they were due to the moon being an opaque body illuminated by the rays of the sun. In the centre of the figure we see the earth half illuminated by the sun and half in darkness, and round it we see the figure of the moon at different positions of its revolution around the earth, each with its illuminated and unilluminated hemisphere marked out by shading the latter. Between the two is the appearance of the illuminated part of the moon as seen from the earth, and constituting its phases. When the moon is at 1, it is between the sun and earth, and its dark side being turned towards us, it is invisible. It is then said to be *New*. As it moves in its orbit, more and more of the illuminated portion of the moon is gradually seen on the earth. When at the position 2, which is some

Phases of the moon.

four days after *new* moon, it appears in the western skies as a small crescent. When at 3, exactly half of the illuminated hemisphere, or one quarter of the entire moon, is seen, and it is therefore said to be at its *First Quarter.* Gradually more and more of the moon is seen, until, on reaching the position 5, the entire illuminated hemisphere can be seen from the earth, and the moon is said to be *Full.* Now the amount of illuminated portion which can be seen slowly lessens, until at 7 again exactly half the illuminated hemisphere is visible, and the moon is said to be at its *Third* or *Last Quarter.* But now the portion of the hemisphere of the moon which can be seen is exactly the half which could not be seen at *first quarter.* Lastly, less and less of the bright portion of the moon can be seen, until it finally disappears, and arriving at 1 becomes again *new.*

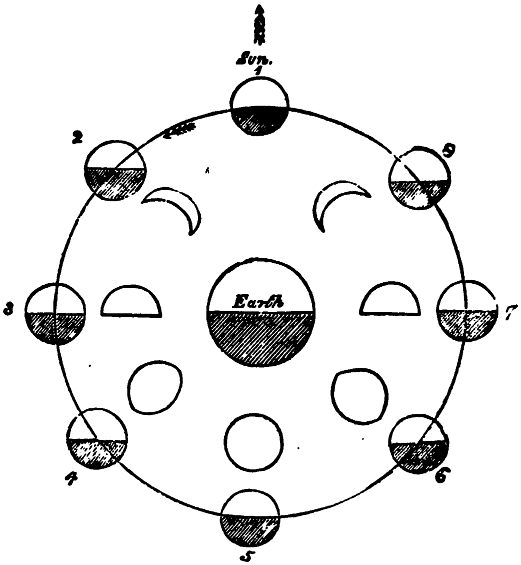


FIG. 5.—THE PHASES OF THE MOON.

Suppose the sun appears to be at *e* on the ecliptic when the moon overtakes it, then, instead of passing in front of the sun and causing an eclipse, the moon will seem to pass below it at *m* if *n* be the descending node, or above it at *m′* if *n* be the ascending node. But suppose the sun seems to be at *n* when the moon overtakes it, then the moon will pass in front of the sun whichever node *n* may be, and an eclipse will happen. *Solar eclipses,* then, only happen when the moon is new. These solar eclipses were regarded as matters of very great importance in early times, so that when their cause was known, much study was devoted to finding out when they would recur. Solar eclipses may be divided into two classes—namely, *total* eclipses, when the entire sun is hidden by the moon, and *partial* eclipses, when only a portion of the sun is so hidden. The former are much the more important. After a time astronomers discovered that in a little more than eighteen years the moon, the sun, and the moon's node all came back to very nearly the same position again, so that the eclipses began to recur in the same order and on the same days as they did before. This period they called a *saros*, and it enabled them to predict the eclipses of the sun with some success.

Solar eclipses. Total and partial.

After some time the ancient astronomers found that the use of this cycle called the *saros* only enabled them to predict a mere fraction of the eclipses of the sun, and that if they wished to be more successful it was imperative that they should master the laws governing the motion of the moon in its orbit or path in the heavens. This knowledge of the motion of the moon was only obtained as the fruit of many years' assiduous study and constant observation.

At an early period it was found that the moon did not appear always to move with the same velocity in its orbit, but that at times it seemed to move faster than at other times, so that one half of its revolution around the earth was performed in a shorter time than the other. This was exactly the same thing as they had discovered of the motion of the sun. If, then, a table is formed giving for any time the place of the moon in the heavens, constructed by supposing it to move uniformly round the earth once in 27 days 7 hours 43 minutes 11½ seconds, it will be found to be seldom correct, because, as the moon moves faster at some times than at others, the moon will be sometimes in front and at other times behind the place it would have had if it had always moved at the same rate. Hipparchus, the celebrated Grecian astronomer, carefully observed the moon, and ascertained at what times it moved faster and at what times it moved slower. He then showed how the correct place of the moon might be obtained by means of a second table which he constructed, and which gave the amount by which it was necessary to correct the place of the moon given by the first table, in order to take into account this unequal rate at which the moon moved in its path in the heavens, or, as it is termed, this inequality in the motion of the moon. He also constructed a similar table to correct the place of the sun, which, as we have seen, also moves with unequal velocities. It was soon found, however, that whereas the sun moved fastest always in the same place in the heavens, this was not the case with the moon, but that the place where it seemed to move fastest, or its perigee, as it is called, was slowly advancing in the heavens; and Hipparchus ascertained that it advanced from west to east right round the heavens in a period of nearly nine years. This discovery he took into account in forming his second table.

Perigee of moon: its motion.

For many years these discoveries of Hipparchus enabled astronomers to predict the great majority of solar eclipses; but they found that the hour at which they occurred seemed exposed to some systematic error. Two hundred and fifty years elapsed before the cause of this was discovered by the famous Ptolemy, a Grecian astronomer, and a worthy successor to Hipparchus (A.D. 100—170). He found that there was still another inequality in the motion of the moon, by which the moon was sometimes in advance and sometimes behind the place assigned to it by the two tables of Hipparchus, by as much as three times its own diameter. This new inequality was subsequently called the *evection*. Careful study showed him how this new inequality acted, and he was enabled to construct a third table which gave him the correction it was necessary to apply to the two tables of Hipparchus in order to obtain the true place of the moon in the heavens.

Prediction of eclipses.

These discoveries enabled astronomers to satisfactorily predict the eclipses of the sun and to fix the time of new and full moon, which was then a matter of considerable importance; and the tables seemed to very satisfactorily represent the place of the moon. Towards the end of the sixteenth century Tycho Brahé discovered two other still smaller inequalities in the motion of the moon, and so rendered the tables still more accurate, though raising their number to five. These two new inequalities were subsequently called the *variation* and *annual equation*.

It was discovered by Tycho Brahé that the moon was not always at the same distance from the earth, because he found that at times it appeared larger than at others, showing that it must be nearer to the earth. He also found that when the moon seemed to be moving fastest it then appeared to be largest, and was therefore nearest to the earth. A most important discovery, as later on will be seen.

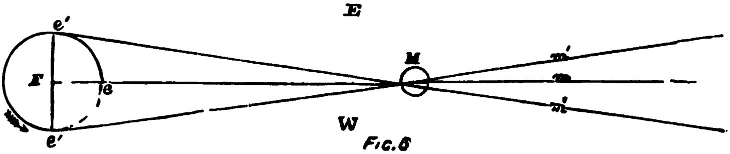


FIG. 6.

Distance of the moon.

A principal point to which astronomers had to devote their attention was to ascertain the distance of the moon from the earth. The first to accomplish this with accuracy was the celebrated astronomer Hipparchus, who fixed its distance as fifty-nine times the radius of the earth. Ptolemy, his successor, made the distance slightly greater. Tycho Brahé determined the mean distance of the moon to be rather over sixty times the radius of the earth.

Parallax.

The method by which these astronomers found the distance of the moon was by ascertaining what is called the *parallax* of the moon, or the apparent alteration in its position when it is looked at from a different position in space. This is shown by fig. 6, where E is the earth and M the moon. Suppose the moon is observed at early morning when it rises, the observer will be at *e′*, and the moon will be seen in the direction *m′*. As the earth rotates in the direction shown by the arrow, the time will arrive when the moon is about to set, and the observer will be at *e″*; then the place of the moon will be at *m″*, or as much to the west of its true place m as in the morning it was east. This apparent change is called the moon's parallax. If we know this parallax or angular displacement EMe', it is easy to draw the triangle MEe', and measure the proportion of EM to Ee'; and in this way, from knowing the parallax, we can tell how many times the radius of the earth Ee' is equal to the distance of the moon ME. In practice it is not necessary to construct this triangle, but by means of trigonometry the distance can be calculated at once. We know now that the mean distance of the moon is equal to 60·27 times the radius of the earth; so we see that Tycho Brahé's determination was not far out.

Apparent diameter and real size of moon.

Tycho Brahé undertook to measure the exact diameter of the moon as it appears to us, and he found that when the moon was at its mean distance its diameter was equal to 31′. It was then easy to find out its exact size, for trigonometry teaches us that a round object seen from a distance sixty times its own diameter will appear to have a diameter of $57\frac{1}{3}'$. The moon is distant from the earth by sixty times the earth's radius; and therefore, if the moon were as large in diameter as the earth's radius, it would appear to be $57\frac{1}{3}'$ in diameter. It is, however, only 31′ in diameter, so that it must be correspondingly smaller than the radius of the earth. As 31 is nearly five-ninths of $57\frac{1}{3}$, so the diameter of the moon is only five-ninths of the radius of the earth. The diameter of the moon is therefore only a little more than one-quarter of the diameter of the earth, so that by geometry its surface is only about one-thirteenth, and its volume one-fiftieth. The moon is therefore much smaller than the earth.

By the beginning of the seventeenth century, it will thus be seen that astronomers had learned a good deal about the motion and size of our satellite.

Lunar eclipses.

Astronomers had known for a very long period that the moon was liable to be eclipsed or become so faint that it nearly or quite disappears. The moon may be shining brightly in the heavens, when it will be noticed that a small portion of its surface looks orange and dusky, as if it were covered with a thin cloud. Gradually this cloudy portion or spot seems to encroach on the disc, as if there were slowly moving across it a round, dusky disc, darkest near the centre, and several times the diameter of the moon. Soon the whole disc of the moon is covered with this dusky shade, so that it becomes so dull that it is often very difficult to detect it, and when seen it looks like a dull greenish orange disc. Suddenly a brighter gleam is seen on the side where the dusky veil was first seen, and soon this portion of the moon bursts forth with its usual lustre and the dusky shade moves gradually off the moon until it quite disappears, and our satellite shines forth with its usual brilliance. This phenomenon is called a total eclipse of the moon. Sometimes the whole moon does not disappear, and a partial eclipse of the moon occurs.

It was soon discovered that these eclipses only occurred near full moon, when the earth was between the sun and moon, so that the moon must be near the shadow cast by the earth. This connection at once served to explain the phenomenon: the moon was eclipsed by passing through the shadow of the earth.

The planets.

It remains to be considered what was known of the planets by astronomers at the end of the sixteenth century. The three superior planets, Mars, Jupiter, and Saturn—called superior because they were farther than the earth from the sun—appeared like bright stars, and their motion in the heavens was studied with ease by noticing how they changed their place among the stars. It was soon found that each of these planets moved in a fixed path in the heavens in the same way as the sun, and inclined at a very small angle to the path of the sun. This path or orbit crossed the ecliptic at a fixed position, and not, as in the case of the moon, at a position which slowly moved. It was easy for them to determine the time which it took these planets to move once round the sun, or make a complete circuit of the heavens. They found their periods to be as under:—

Mars,	1 year 321 days 23 hours 30 minutes.
Jupiter,	11 years 317 days 14 hours 2 minutes.
Saturn,	29 years 174 days 5 hours 16 minutes.

Distance of the planets.

It remained to be ascertained how far the planets were from the sun. We have already seen how the early astronomers found out the distance of the moon by determining its *parallax*, or apparent change in position when it was seen from opposite sides of the diameter of the earth. They tried to ascertain the distance of the planets by the same method, but soon found that these latter did not appear to sensibly alter their places when thus observed. It was evident, therefore, that the planets were much more distant than the moon, and that it would require a much greater change of place than one diameter of the earth to see any change in the place of the planets. This change they found in the motion of the earth, as we shall see.

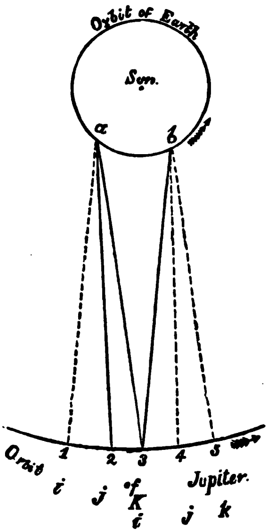


FIG. 7.

Let fig. 7 represent the orbit of the earth and a portion of the orbit of the planet Jupiter. Let *a* and *b* be the position of the earth on its orbit on two days, with an interval of two months between them; and on the first day let the position of Jupiter be marked by 2, so that on the second day Jupiter will have advanced in its orbit to 3. Now, as the stars are so distant that they always appear in the same direction, the stars *i j k* in the direction 1 2 3 on the first day will seem in the direction 3 4 5 on the second day, Evidently, therefore, instead of the planet Jupiter seeming to move onwards from the star *j* to the star *k*, as it would do were the earth stationary at *a*. it will seem to move backwards to the star *i*. Jupiter, in fact, on the second day will seem to be behind its proper place by the distance between 3 and 5 (or 1 and 3), and by geometry this distance will be equal to the distance between *a* and *b*, through which the earth has moved. Now, by geometry we know how far off this distance between *a* and *b* must be placed to make it look as large as the angle between 3 and 5, an angle in the case of Jupiter of about 13°, so that this distance will be the distance of the orbit of Jupiter from the orbit of the earth. It is just 4½ times the length of the distance between *a* and *b*, so that the distance of 4 from *b* (or of 2 from *a*) will be 4½ times the distance of *a* from *b*. From geometry we learn that as the sun moves nearly 60° in two months, the distance between *a* and *b* must be nearly equal to the distance of the earth and sun, so that from the orbit of the earth to the orbit of Jupiter is nearly 4½ times the distance of the earth from the sun, and the distance of the orbit of Jupiter from the sun must be a little less than 5½ times the distance of the earth from the sun.

In this manner astronomers were able to fix the distance of these three superior planets from the sun. They found them to be—

Mars, 1·53 times that of the earth, or nearly 1½.
Jupiter, 5·20 „ „ „ 5¼.
Saturn, 9·54 „ „ „ 9½.

Geocentric and heliocentric position of the planets.

We learn, therefore, that the position and motion of the planets, as seen from the earth, differ from what they would be if seen from the sun; the former are said to be their geocentric position, and the other their heliocentric position, and astronomers, in studying the motion of the planets, have to reduce their geocentric to their heliocentric position by means of trigonometry.

It was not long before they learnt that the planets appear to move round the sun at times quicker than at others, just in the same way as the sun seems to move quicker in winter than in summer, because the earth so moves. They were able to ascertain the exact part of the heavens where the planets moved fastest and that where they moved slowest, and they found that these places remained fixed, and did not alter as in the case of the moon.

About the physical nature of the planets astronomers then knew nothing, but by analogy they supposed they were spherical bodies like the earth.

Inferior planets.

The planets Mercury and Venus were termed the inferior planets, because they lay between the earth and the sun, and were never seen very far from him, appearing at one time on the west of the sun and visible only at sunrise, and at others appearing on the east of the sun and to be seen solely at sunset. Occasionally, Venus became so bright that astronomers could see her in broad daylight, but this was not commonly the case. It was easy to determine the distances of these inferior planets from the sun, by merely seeing what was the greatest angular distance they appeared on either side of him, and by means of geometry they at once found out how far the planet must be from the sun to make it appear at this angular distance. In this way they found that Venus was never more than 48° from the sun, nor Mercury more than 28°. Their distances were therefore—

Mercury, 0·44 times that of the earth, or nearly $\frac{3}{7}$,
Venus, 0·73 „ „ „ $\frac{5}{7}$,

whilst the time they took to revolve once round the sun was—

Mercury, 87 days 23 hours 15 minutes.
Venus, 224 days 16 hours 49 minutes.

The constellations.

From a very early period the stars had been divided into different groups, or constellations as they were called, each of these constellations being supposed to represent some imaginary figure, and bearing a special name. Thus the ecliptic, or apparent path of the sun, was divided into twelve constellations. These were as follows :—

I. Aries, the Ram.
II. Taurus, the Bull.
III. Gemini, the Twins.
IV. Cancer, the Crab. Two of the stars in this constellation were called by the Romans Aselli, the Asses, and a nebulous cluster close to them was known as Praesepe, the Manger.
V. Leo, the Lion.
VI. Virgo, the Virgin.
VII. Libra, the Balance.
VIII. Scorpio, the Scorpion.
IX. Sagittarius, the Archer.
X. Capricornus, the Goat.
XI. Aquarius, the Water-bearer.
XII. Pisces, the Fishes.

The remainder of the heavens was divided into some thirty to forty constellations in a very similar manner.

The different stars were also classed into magnitudes, the brightest being said to be of the first magnitude, the next brightest of the second magnitude; then came the third magnitude, and so on up to the sixth magnitude, which are the faintest stars that can be seen with the naked eye. A star of the first magnitude is about twice and a half as bright as one of the second magnitude—which is, in turn, about twice and a half as bright as those of the third magnitude. The stars which cannot be seen by the naked eye, but which can be seen in a telescope, are now divided in the same way into stars of the seventh, eighth, and ninth magnitude. Those of the tenth and eleventh magnitude are so faint that they require powerful telescopes to see them.

Celestial longitude and latitude.

Hipparchus and other astronomers had carefully determined the places of the stars in the heavens by measuring their distances parallel and perpendicular to the ecliptic ; and these distances they called the longitude and latitude of the star. They measured the longitude of the stars from the place where the ecliptic crossed the equator, from the south to the north ; and this point was called the *vernal equinox*. Before long they discovered that this point was not fixed in the heavens, but slowly moved backwards by 36″ a year. This was called the *precession* of the equinoxes. Subsequently astronomers obtained a far more accurate value of this quantity, Tycho Brahé making it 51″ per annum.

Such, then, was the extent of the knowledge of astronomy which we might have gained at the beginning of the seventeenth century by studying the work which had been accomplished by our predecessors. All the more striking celestial phenomena had been explained, and a good deal had been learned about the distances and motions of the planets; it being remembered that, the telescope being unknown, all the observations had to be made by the naked eye, so that distances in the heavens of less than 5′ were very difficult to see or measure. Place a penny at the summit of a very lofty house and look at it, and you will understand that 5′ is a very small quantity in the heavens. Tables had been constructed from whence could be taken the position of the Sun, Moon, and Planets, but these tables gave places which were often a whole degree out.

CHAPTER II.

EARLY CONTRIBUTIONS TO ASTRONOMY.

Kepler's Laws—Galileo and the Telescope—Phases of Venus—The Satellites of Jupiter—Eclipses of the Satellites—Improvement in Astronomical Telescopes—Belts of Jupiter—Telescopic appearance of Saturn—Extraordinary variations in the appearance of Saturn—Saturn's Moon—Appearance of Mars—Telescopic appearance of the Moon—Lunar Maps—Seas and Mountains—Inhabitants of the Moon—Spots on the Sun—Rotation of the Sun—Bright markings on the Sun—Transits of the inferior planets—First Transit of Mercury—First Transit of Venus.

IT has been already mentioned that at the commencement of the seventeenth century it was known that the earth and planets revolved round the sun, and that sometimes they moved faster than at others, whilst it was even determined where they moved faster or slower. But according to what laws did the planets thus move? A momentous question: for what further progress could theoretical astronomy be expected to make, until this problem had been solved?

The first great contribution to astronomy during the seventeenth century was the discovery of the true answer to this momentous question. It was the discovery by the illustrious Kepler of the famous laws governing the motion of the planets round the sun—a discovery which has rendered his name immortal. Kepler was born in Southern Germany in 1571, and was an enthusiastic astronomer and indefatigable worker. Gifted with great ingenuity, he was a most energetic theorist. With wonderful patience and ingenuity he invented hypothesis after hypothesis which he thought might prove to be the true laws governing the motion of the planets. Turning to the long series of careful observations made by Tycho Brahé, he, with great labour, carefully reduced these so as to obtain the true position of the planets at different times. He then rigidly tested each of his hypotheses by comparing their result with

Kepler's laws.

these observations of Tycho Brahé. But each of these hypotheses broke down under the rigid scrutiny ; this one failed to explain this fact, another failed to explain some other fact, and a third, whilst it accounted for the observed motion of Venus, would not account for that of Mars. Nothing daunted, he rejected them all, and contrived yet other hypotheses. But these were not more successful. For fifteen years he pursued his arduous work, and without success. Mars, of all the planets, proved to be the most troublesome, and yet the observations of this planet which had been made by Tycho Brahé were numerous and accurate.

At last, however, his perseverance was rewarded, and he discovered his famous first law,—

I. *That the orbits of the planets are ellipses having the sun in one of their foci.*

Let us inquire further into the meaning of this law.

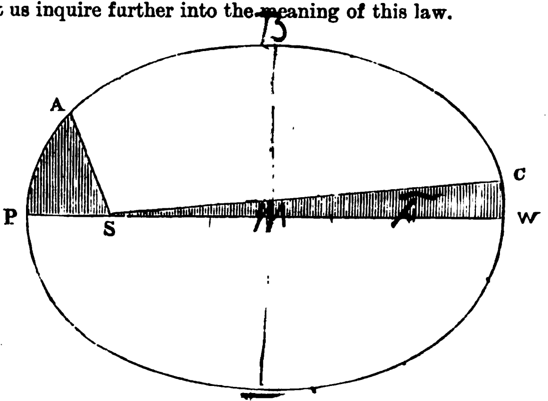


FIG. 8.—KEPLER'S SECOND LAW ILLUSTRATED.

An ellipse is a closed curve, not unlike a flattened circle; and an illustration of an ellipse is shown in fig. 8. The longest diameter of the ellipse, P W, is called its *major axis*, and the shortest diameter, B D, is called its *minor axis*. On the major axis of every ellipse are two points called its *foci*, and in the figure marked S T. These foci are placed at equal distances from the centre of the ellipse, M, and they possess certain geometrical properties which need not be described now; but the most important is the fact that the distance of any point on the circumference of the ellipse from one focus, added to the corresponding distance from the other focus, is always the same, and equal to the major axis, no matter on what part of the circumference of the ellipse the point is situated. This property enables us to draw the ellipse with ease, for we have merely to take a piece of silk the length of the major axis, fasten each end to a pin inserted in the foci of the ellipse, and pressing the point of a pencil against the piece of silk, move it along, keeping the silk tight. The distance of each focus of the ellipse from

Kepler's first law.

the centre, in parts of half the major axis, is called the *eccentricity* of the ellipse. If, therefore, the distance M P, or semi-major axis as it is called, be 10, and the distance M S be 6, the eccentricity of the ellipse is said to be 0·6, or three-fifths.

Having given this account of the curve called an ellipse, we can now explain Kepler's first law. It says that every planet moves round the sun in the circumference of an ellipse, and that the sun is placed in a focus of this ellipse. In fig. 8 suppose S to be the sun, then astronomers call the distance M P the *mean distance* of the planet; it is half the greater diameter of the ellipse, and they define the form of the ellipse by stating what is its *mean distance*, and what is its *eccentricity*, or the distance (S M) of the sun from its centre. When these two quantities are known, we can easily draw the ellipse in the manner shown above. The ellipse shown has an eccentricity of 0·60, which is thrice that of the orbit of Mercury. They also call that point of the ellipse (P) which is nearest to the sun the *perihelion* of the orbit of the planet; and the opposite point (W), where the planet is farthest from the sun, is called the *aphelion* of the orbit of the planet. These names can easily be remembered.

This discovery of Kepler's was a grand discovery, for it showed astronomers what was the real orbit of a planet, and at once did away with all those complicated hypotheses by which the earlier astronomers had tried to explain the motion of a planet. But this was not all; it was also necessary to know at what rate the planet moved in this orbit. Did it move steadily round always at the same speed, or did it move rapidly in one part and slowly in another? This also was answered by Kepler, by his discovery of his second law, which says:—

II. *That a line joining the planet and the sun sweeps over equal areas in equal times.*

Kepler's second law.

The meaning of this law is shown by fig. 8, where S W is a line joining the sun and planet, or, as it is called, the *radius vector* of the planet. Now, according to Kepler's second law, the planet would move over the spaces W C and A P in equal times, because the shaded area enclosed between the two lines S W and S C is equal to the area enclosed between the two lines S A and S P. From the figure it is evident that the planet moves fastest when near the sun and slowest when far from the sun.

Not only did these laws account for the motion of the planets, with their alternate slow and quick motion, but they accounted to a certain extent for the motion of the moon, inasmuch as they explained why Hipparchus' second table was required. The motion of the node and perigee of the moon showed that the ellipse in which the moon moved was not stationary, like that of the planets, but was slowly moving in periodical revolutions. Kepler was unable to account for the other inequalities in the motion of the moon—namely, the evection discovered by Ptolemy, and the variation and annual equation discovered by Tycho Brahé.

These two famous laws were announced by Kepler in a great work published in 1609, and called "De Motibus Stellæ Martis," or, rather, that is the end of its long title, and is the name by which it is generally known. They were of immense value to astronomy, and laid the foundations for its subsequent great advance. Kepler was not, however, content with these two laws, for he clearly saw that there must be some law connecting the distances of the planets and the time they took to move round the sun. The discovery of this law was the goal of his work, and encouraged by his success, he redoubled his efforts to discover this law. To determine the distance of a planet by direct observations from the earth was a very difficult operation, and no great accuracy could be expected; but to find out the average time they took to go round the sun was very much easier, and if the law connecting these two could be discovered it would be easy to find the distances of the planets with great accuracy. The discovery of this law was not, however, to be made at once. Kepler imagined all sorts of laws connecting the distance and period of revolution of the planets, and carefully tested all these laws by a laborious comparison with the result of Tycho Brahé's observations; but not one proved to be correct. Years went by, and still his efforts were unsuccessful. Nine years were spent in this labour; and then, on the 8th May, 1618, he succeeded, and was enabled to triumphantly announce his third famous law:—

Kepler's third law.

III. *That the squares of the periods of revolution of the planets are in the same proportion to each other as the cubes of their mean distances from the sun.*

This law requires no illustration, and shows that a planet which is twice as far as another will require $\sqrt{(2)^3} = \sqrt{8} = 2{\cdot}83$, or nearly $2\frac{5}{6}$ times as long a period to revolve round the sun. Twenty-six years had been spent by Kepler in these researches, but he had his reward in the discovery of those three famous laws which regulate the motions of the planets, and which have served as the groundwork of modern theoretical astronomy. And it is well worthy of notice that it was by the assiduous study of that very planet Mars, which had been his great trouble, from its motion being inconsistent with his earlier hypotheses, that Kepler was able to deduce the true laws which regulate the motions of the members of the solar system, and so render his name immortal as one of the grandest discoverers the world has seen. Yet, like all grand discoveries destined to revolutionise science, these famous results of Kepler did not meet with general attention. Men do not like to have to change opinions they have long held, and which are sanctioned by the great names of their predecessors. The greatest practical astronomer of the time, Gassendi, of Aix in France, did not attach much importance to these discoveries. Many refused to credit them; others, like Riccioli, undervalued them. Bullialdus was the first to introduce them into practical astronomy, and Horrocks was the first to properly appreciate their value. The succeeding generation of astronomers recognised their importance, and, led by Hevelius, Huygens, and Picard, universally adopted them.

The next advance in astronomy was of a different nature, yet of the highest importance. In Tuscany, in Northern Italy, there was living at this period the celebrated philosopher Galileo Galilei. Born at Pisa in 1564, he had rendered his name famous by his great discoveries in mechanical science, in what is now known as statics and dynamics. In the spring of 1609 Galileo was staying in Venice, when he learned

Galileo and the telescope.

from a friend that a Dutch instrument-maker had succeeded in making a telescope, by which distant objects appeared much larger. On his return to Padua, where he was then living, he thought over the subject, and soon saw that the principle of this discovery must depend on the refraction of light by glass lenses. By experimenting with a convex lens and a concave lens fitted into a tube, he succeeded in making a telescope which magnified three times; this instrument created a great sensation in Venice. Galileo next devoted his whole energies to making a much more powerful telescope, and proceeded to grind and polish lenses with which to construct one. After much labour, he succeeded in making one which magnified as much as eight times. Finally, by labour and perseverance, he was able to construct a telescope which magnified as much as thirty times, and it was with this instrument that his famous discoveries were made.

Galileo at once turned his telescopes on the celestial bodies, and was rewarded by brilliant discoveries, thus inaugurating the magnificent series of telescopic investigations which have rendered physical astronomy so grand a science. Even with his smaller telescopes he observed a great difference in the appearance of the planets and the stars. The former appeared as distinct discs of sensible magnitude, whilst the latter were like very minute tiny glittering points, much smaller than they seemed to the naked eye.

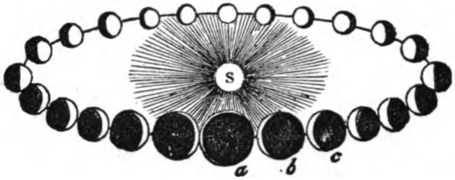


FIG. 9.—PHASES OF VENUS.

Phases of Venus.

Up to this time the opponents of the theory of the revolution of the earth round the sun used to urge that if this theory were true, and the planets simply reflected the solar light, the planets Mercury and Venus ought to show phases resembling the phases of the moon, and should vary much in size. This is quite true, as will be seen by a study of fig. 9. When Venus is between the earth and the sun, as at *a*, almost the entire body of the planet should be in shadow, and at most a tiny crescent of light be seen. As the planet moved round the sun first to *b* and then to *c*, and so on, it would become more distant, and so look smaller, whilst more of the enlightened side of the planet would be rendered visible. Soon half the illuminated hemisphere of the planet would become visible, and the amount which would be seen of the bright side of the planet would go on increasing, until when farthest from the earth, practically, the whole disc would be seen like the full moon. Of course, under these conditions the planet would appear beyond the sun, and generally so close as to be invisible; but at times it might be seen either over the sun or under it. As the planet moved on in its orbit exactly the reverse phenomena would occur, as shown by the figure. The advocates of the Copernican theory quite saw the truth of this, but replied that these planets might exhibit phases, but that we might not be able to see them. Not a very satisfactory answer, though as it happens it is really the true reason.

When, therefore, Galileo had made his large telescope, he turned it on Venus, and carefully studied the appearance of the planet. He commenced his observations in September 1610; and the planet appeared like the moon at its quarters, and gradually became more and more crescent. He was soon obliged to stop his observations, for Venus was unfavourably placed, but Galileo had seen enough to show him that Venus did present phases resembling the moon. This he published in the form of an anagram. In the subsequent year Galileo was enabled to resume his observations, and announced to the world that Venus did present the same phases as the moon—a great triumph for the Copernican theory.

Discovery of the satellites of Jupiter.

The first great discovery made by Galileo with the telescope he had constructed was not, however, the phases of Venus. It was in connection with Jupiter. On January 7, 1610, Galileo observed Jupiter with his largest telescope; he noticed it presented a round disc of considerable size—nearly as large, in fact, as the moon when seen by the naked eye. Close to Jupiter he noticed three bright stars, all arranged in a straight line, and two on the left side of the planet and one on the other. Galileo was struck by their bright appearance and peculiar position with respect to the planet. The next day he again looked at Jupiter, and to his astonishment the three stars were still there, but very differently arranged, for they were all three on the same side (the right) of the planet, and much closer together. This struck him as most remarkable, and he anxiously awaited the next night to still further observe these remarkable stars. The night, however, was cloudy, and he had impatiently to wait until the night following. Quickly turning his telescope on Jupiter, to his amazement there were only two stars, and they were on the opposite (or left) side of the planet to what the three had been on the 8th, but just in the position of the two he had seen on the 7th. It seemed to him impossible that any motion of the planet could produce such extraordinary changes, and he began to suspect that the stars themselves were moving. On the 11th there were still only two stars, and both on the left, but one seemed bigger than the other; the third seemed to have vanished. On the 12th he again turned the telescope on Jupiter: there were the two stars, but now one was on each side of the planet; and whilst still looking at them, he suddenly saw a faint point of light quite close to the east side of the planet. Struck with astonishment, Galileo looked again and again. No, he was not deceived; it gradually became brighter and brighter, and moved farther and farther from the planet, and to his joy it was the missing third star. Galileo watched it anxiously, and saw it move farther and farther still from the planet. He felt that there could no longer be any doubt as to the nature of these stars: evidently they moved round the planet,—they must be satellites. No longer was the earth unique: Jupiter had moons!

On the 13th he saw four stars, one on the left and three on the right. Had Jupiter more than three moons? Subsequent observation showed him that Jupiter had four moons, but no more. He named them the Medicean stars, after the famous rulers of Florence, and announced his discovery to the world. The importance of the discovery was at once appreciated by philosophers, who saw in Jupiter a miniature solar system. Astronomers were able to retort on those who objected to the theory of the solar system as discovered by Copernicus and Kepler, "You said, 'If your theory of Copernicus be true, as the earth has a moon, lo, Jupiter should have four!' Behold, Jupiter has four!"

Astronomers immediately set to work to determine the distances of these satellites, and the time they took to revolve round Jupiter. They found that the nearest satellite, I., was distant from the centre of Jupiter by 6 times the radius of that planet, and took 1 d. 18 h. 28 m. to revolve round it; that satellite II. was distant 9⅔ times the radius of Jupiter, and took 3 d. 13 h. 13 m. to revolve round it; that satellite III. was distant 15⅓ times the radius of Jupiter, and took 7 d. 3 h. 43 m. to revolve round it; and that the farthest satellite, IV., was distant 27 times the radius of Jupiter, and took 16 d. 16 h. 32 m. to revolve round the planet.

As the satellites moved round Jupiter, it was soon seen by astronomers that at times they passed behind the planet, and at times they must pass in front; in either case they were then invisible. At times, however, they disappeared before coming up to the planet, and reappeared also at some distance from the planet. It was soon seen that this arose from Jupiter casting a shadow.

Eclipses of the satellites.

In fig. 10 we have a plan of the Jovian system, with Jupiter in the centre and the orbits of its four satellites round it. If the earth be in the same direction as the sun, the satellites seem to disappear and reappear always at the edge of the planet; but this is no longer the case if the earth be a little on one side of the sun, as it almost always is—say in the direction J E, as it is twice a year. We see that the first satellite disappears in the shadow at 1‴ before it reaches the edge of the planet, but reappears from behind the edge of the planet at 1. The same is true of the II. and III. satellites. The IV. satellite disappears in the shadow at 4‴ and reappears at 4″ on the same side of the planet, then disappears at the edge of the planet at 4′, and reappears at the opposite edge at 4. When a satellite is lost in the shadow of the planet it is said to be *eclipsed*; when it disappears behind the edge of the planet it is said to undergo *occultation*; whilst when the satellite passes in front of the planet there is said to be a *transit*.

Astronomers soon found that the satellites and planet appeared to be equally bright, so that when the satellite passed in front of Jupiter, and ought to be seen moving across the disc of the planet, it would not be visible, for it would appear just as bright as the rest of the surface of the planet, and could not be distinguished from it. But they also saw that the moons would cast a shadow as well as the planet, and that wherever the shadow of the satellite fell on the planet it would appear as a black spot. These black spots or shadows ought to be visible in transit. Galileo and his contemporaries looked attentively to see these shadows, but entirely without success, for, as we now know, their telescopes were not sufficiently powerful.

After a time more perfect telescopes were gradually made, and made on a slightly different principle. Galileo's telescope, as already stated, consisted of a large convex lens at one end and called an object-glass, whilst at the other end was a small concave lens called an eyepiece, because it is put next to the eye. It is not easy to make these tele-

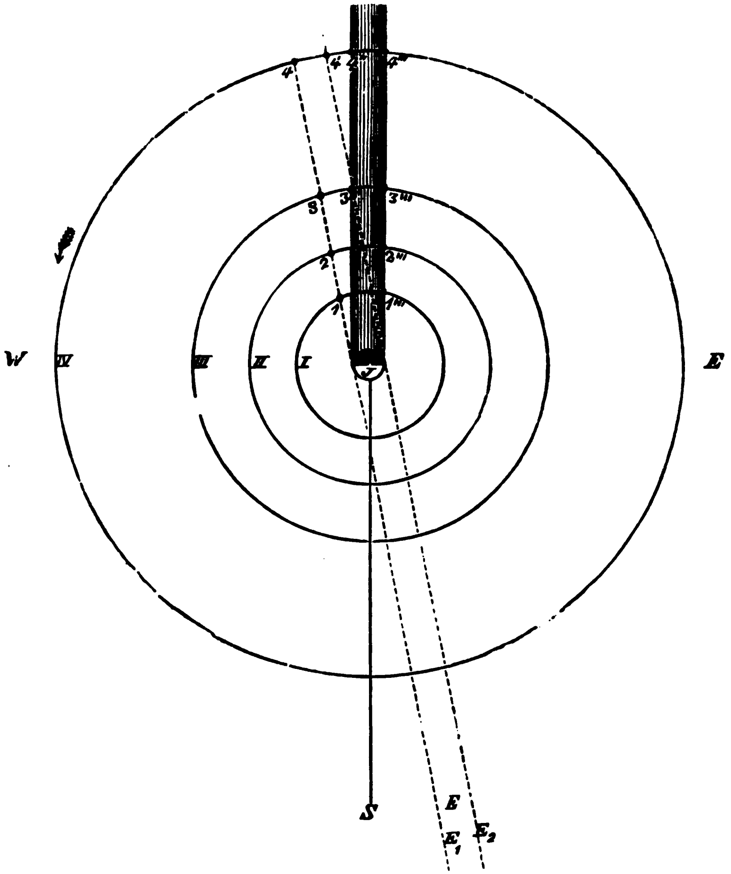


FIG. 10.—THE JOVIAN SYSTEM.

scopes very powerful, though they may be made to magnify fifty times. The illustrious Kepler suggested a modification of this design, which was to use a small powerful convex lens as an eyepiece instead of a concave lens. The first to use a telescope of this kind was the Jesuit Scheiner, who in 1630 constructed the first Keplerian telescope. This was found to be a decided improvement, and by the middle of the century they superseded the Galilean telescope. Huygens, a distinguished Dutch astronomer, still further improved this design by using an eyepiece made of two convex lenses instead of one. Huygens acquired by long practice great skill in grinding and polishing lenses for telescopes, and for many years was the great authority on their construction. His own favourite telescopes were one of 3 inches aperture and 12 feet focus, magnifying 48 times; and another of 3½ inches aperture, 23 feet focus, and magnifying 132 times. To make these telescopes perform well, it was found to be necessary to give the object-glass a focus of 3 to 6 inches for each time the telescope was to magnify. A telescope which was to magnify 60 to 80 times had to have a length of 20 to 30 feet, and an object glass of from 2½ to 3 inches in diameter. Later on, in about 1670—1700, when they wanted to use magnifying powers of 150 to 250, they were obliged to use object-glasses of 4 to 6 inches diameter, and with a focus of 60, 90, or 120 feet, or even at times 200 to 300 feet. These giants could not be mounted in tubes. The object-glasses were placed therefore on a stand at the top of a very lofty pole, and moved about by cords, whilst the eyepieces were mounted on smaller movable stands placed on the ground. These telescopes were very inconvenient, and required much experience to use them. Later on, in the early part of the eighteenth century, Campani, of Rome, advanced still further in the art of constructing telescopes; and telescopes of 30 to 50 feet in length were made, which magnified 150 to 200 times, and had apertures of 3 to 4 inches. The telescopes in general use were from 12 to 25 feet in length, magnified 80 to 120 times, and had object-glasses with apertures of 2 to 3 inches.

Improvements in astronomical telescopes.

Early in 1620, Zucchi, an Italian Jesuit, was in possession of a more powerful telescope than that employed by Galileo; and on May 17th, 1620, he examined Jupiter, and dimly saw two greyish bands or belts stretching across the planet, which hitherto had been supposed to be a uniform dull yellow disc. Three years later, Fontana, a Neapolitan astronomer, saw three such belts. Grimaldi, an Italian philosopher, in 1648 devoted much time to watching Jupiter, and he discovered that these belts were nearly parallel to the plane of the orbit of the planet. He also saw some dim dusky spots on Jupiter. Later the belts and spots were frequently seen, and found to be variable in their position and number. Hooke, a celebrated astronomer, even suspected that the planet must revolve on an axis to account for the changes he saw.

Belts of Jupiter.

When Galileo examined the planet Saturn with his most powerful telescope, he was amazed to find that it was entirely unlike any of the others, and appeared to be not one but three bodies. It seemed to consist of a large central body, about half the size of Jupiter, with two smaller bodies on each side of it, so that it appeared as shown

Telescopic appearance of Saturn.

in fig. 11. Later on in the year he was surprised to find that the lesser bodies had become decidedly smaller than in the early part of the year. In 1611 his observations showed him that the two lesser bodies were very much smaller, and they continued to grow smaller and smaller, until, to his great dismay, they entirely vanished in 1612. Galileo felt much alarmed as well as amazed, for he thought this extraordinary phenomenon would cast much discredit on his other observations, as it seemed impossible that so unaccountable a thing could be other than an illusion.

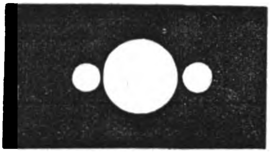


FIG. 11.

Extraordinary variations in appearance of Saturn.

Later on these secondary bodies reappeared, which showed that Galileo's observations were quite trustworthy, and the appearance of this extraordinary planet was repeatedly examined by astronomers. As soon as more powerful and perfect telescopes were constructed, some further information was obtained, which only seemed to render the phenomenon more mysterious. Gassendi, a French astronomer, devoted much time to drawing Saturn. He saw the planet at times as in fig. 11, but at other times the lesser bodies grew so large that they seemed to join the central body, and the whole to look like an ellipse, in which he seemed to see two very dusky crescent-shaped markings, as shown on fig. 12. Later on the planet appeared as if it had two handles to it; and these handles, or *ansæ*, which were small when first seen, grew gradually larger, until they were like fig. 13, and then became smaller until they disappeared. In every fifteen years the whole appendages disappeared, and Saturn seemed a round planet like Jupiter.

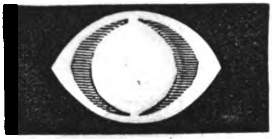


FIG. 12.

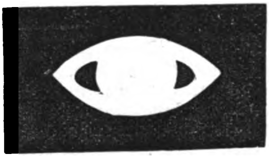


FIG. 13.

Their explanation by Huygens.

For nearly half a century these extraordinary variations in the shape of the planet perplexed astronomers, and many were the ingenious but fanciful explanations which were advanced to account for these changes. In 1656 Huygens, the famous Dutch astronomer, published a small pamphlet, in which he gave, under the form of an anagram, the true explanation of the phenomenon, and in 1659 he explicitly announced his discovery in a work entitled "Systema Saturnium." According to this explanation, the planet is surrounded by a thin flat ring, separated from the body of the planet by a small interval, and inclined to the ecliptic, as shown in fig. 14. As the ring is very thin, when the edge is turned towards the earth the ring becomes invisible, and the planet appears quite round, like Jupiter; and it will also be invisible when the dark side of the ring is turned towards the earth, as will sometimes happen for a short period. The same explanation also accounts for the changes in the appearance of the ring, which is always seen foreshortened into an ellipse; but the amount of foreshortening being variable, at times the ellipse will look broad and at other times very narrow.

On March 25th, 1655, Huygens was observing Saturn with his 12-foot telescope, of his own manufacture, and having, as already mentioned, an aperture of 3 inches, and provided with a power of 48, when he saw a small star on the west of the planet, and in the same plane as the ring, and another on the east, but not in the same plane. For some reason Huygens was led to suspect that the former star might be a satellite, so on the next day he again examined Saturn. He was rejoiced to see that it was still in nearly the same position, though Saturn had moved some distance to the west, and the star which had been seen to the east was now much farther off. As the western star had evidently moved with the planet, it was obvious that it must be connected with it and be a satellite. Further observation showed him that this was correct, and that the satellite revolved round Saturn in rather less than 16 days—namely, 15 d. 23 h. 13 m. Saturn, then. had a moon as well as the earth. It was moreover unique in possessing a ring.

Saturn's moon.

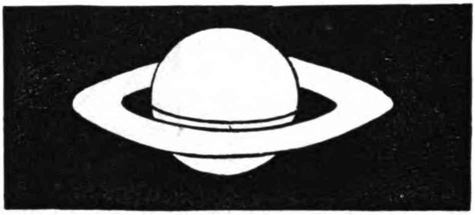


FIG. 14.

The earlier observers were unable to make out much on the planet Mars. Galileo merely saw a red disc of very variable size: when the planet was in opposition or nearest the earth, the earth being between the sun and planet, it appeared two-thirds the size of Jupiter; but when farthest from the earth and near the sun, which then lies between the planet and the earth, the planet looked only like a rather large red star. Subsequent observers saw little more, though in 1636 Fontana, the Neapolitan astronomer, observed a grey spot on the planet which seemed to change position, so that he was led to suspect that the planet rotated on its axis.

Appearance of Mars.

Nor could the early observers make much out of the planets Mercury and Venus; they confirmed the discovery made by Galileo, that these planets had phases like the moon, and were variable in size as their distance from the earth varied, but they saw little if anything more.

When Galileo turned his telescope upon the moon, he was delighted to find it to be a body having much resemblance to the earth. He found its surface to be divided into dark grey level regions not unlike lunar seas and oceans, separated from each other by brighter elevated tracts having all the appearance of being continents. He traced straits and broad arms uniting the different seas; he found them bordered in places by rugged and frowning cliffs, and in others by gradually shelving beaches; he saw bays indenting the continents and capes penetrating the seas. There the sea seemed broken by an island, here the land seemed to enclose a level lake. In one spot he saw lofty mountains towering thousands of feet above the plains, and in another place the surface was broken by numerous valleys; here rough and precipitous, there gentle and smiling. Everything pointed to the moon as the companion to the earth—another world.

Telescopic appearance of moon.

More closely studied, the moon seemed to be a region of extinct volcanoes; on all parts of the surface were seen immense craters, and radiating from these craters appeared long streaks of a bright grey colour as if they were old lava streaks. These lunar volcanoes were evidently extinct, for in places they were ruined, and no trace of an eruption could be detected.

Scheiner, Gassendi, and Langrenus, a Spanish astronomer, devoted care and attention to studying the surface of the moon, and drew its appearance as seen under different illuminations: for it was soon found that the moon altered very much in appearance as the illumination varied. Those parts of the moon which were near the border, the *terminator* as it is called, which separated the illuminated from the unilluminated portion of the moon, were seen to cast long shadows, and the mountains stood up in bold relief; whilst the regions near the centre of the bright portion of the moon appeared without shadows, and looked like white and grey markings on a yellowish ground.

Hevelius, a citizen of Dantzic, and one of the most famous observers of the seventeenth century, carefully examined the surface of the moon with a telescope magnifying forty times. After four years' study he employed his observations for the purpose of constructing a complete map of the moon. For the sake of reference he named some of the principal spots, giving them a name after some fancied resemblance to a region on the earth. Thus a great chain of mountains he called the Alps, another the Apennines, etc. This map was published in 1647. Four years later Riccioli of Bologna, an Italian Jesuit, published another map, founded partly on his own observations and partly on the observations of Gassendi. He entirely rejected the nomenclature of Hevelius, and named the principal spots after distinguished astronomers and mathematicians. His principle of nomenclature has been retained to the present day.

Lunar maps.

These astronomers pointed out that the great grey plains seen on the moon were very probably the beds of seas, but were not seas, for they were not filled with water. In this respect therefore the earth and moon differed, for the latter had no seas. That there was water on the moon they thought probable, and one of them pointed to some smooth very dark mountain rings which he thought were lakes. They also showed that the moon had not a dense atmosphere like ours, and that clouds seldom,

Seas and mountains.

if ever, obscured the surface,—so that it could not rain. Nor were there forests of green trees; yet, as one philosopher remarked, the lunar trees might have grey leaves, and both Hevelius and Riccioli noticed regular variations in the great grey spots or regions which existed on the moon. The conclusion was obvious that, though the moon and earth had many analogous features, yet the one was not a mere copy of the other.

One important result of these observations remains to be noticed: they discovered, by comparing the drawings of the moon made by Galileo, Scheiner, and Langrenus with their own, that the moon always turns the same face to the earth, so that we only see one-half of the entire moon, the farther hemisphere being invisible from its being always turned away from the earth. This was a great disappointment, and opened a wide field for speculation. What does the other side of the moon look like? Some urged that it was most likely just the same as the side we see, but others would not listen to such a suggestion. They drew wondrous pictures of lakes and seas, of luxuriant forests, of gorgeous flowers, of winding rivers, and smiling valleys. They crowded it with various species of animals, peopled it with inhabitants, built grand cities of marble and gold, covered its seas with boats and stately ships. This, they cried, must be the nature of the other side of the moon—that side which we, unfortunate mortals, shall never see.

Inhabitants of the moon.

At this time, and in fact until the beginning of the nineteenth century, most astronomers believed the moon to be inhabited. Some, more enthusiastic than the rest, proposed that great fires should be made by which signals could be sent to the lunar inhabitants. One suggested that the great desert of Sahara was made for the express purpose of sending such signals, and demanded that a message should be written on it with letters of black sand several miles long and a mile broad. Another suggested that the forty-seventh proposition of the First Book of Euclid should be constructed on a very large scale on some level region, as he felt positive that the lunar philosophers must have had to solve that problem by this time, and would recognise it. Many other fanciful ideas and plans were suggested.

We shall see how the progress of science has modified these ideas.

Spots on the sun.

When the sun was studied with the telescope, a number of small black spots were discovered on its surface, these spots being of most irregular size and form. The discovery seems to have been independently made, towards the end of 1610 and beginning of 1611, by no less than four observers: John Fabricius, a German astronomer; Scheiner, a Jesuit and professor of mathematics at Ingolstadt in Bavaria; Galileo in Italy; and Hariot, the celebrated English mathematician. The discovery excited much astonishment, and many philosophers were incredulous, for it was at the time supposed that the very nature of the sun was irreconcilable with the existence of solar spots. To these early observers the spots seemed merely irregular black marks on the surface of the sun, and they soon discovered that they were slowly moving across the solar disc. When first seen they were small and indistinct, and moved slowly; but as they approached the centre they appeared to move faster, and seemed larger. Fabricius pointed out that this indicated that the solar spots were actual markings on the surface of the sun, which had a uniform rotation on its axis, for then the ordinary rules of perspective would produce the changes noted in the apparent size and rate of motion of the spots. Galileo made the time of the rotation of the sun about 26 days, and remarked that it rotated about an axis making a small inclination with the perpendicular to the ecliptic. Scheiner, who studied the solar spots for many years, made the rotation about 24½ days, and found 7° for the inclination of the axis to the perpendicular to the ecliptic. Modern observations make the period of the rotation 25⅓ days and the inclination of the axis 7⅓°.

Rotation of the sun.

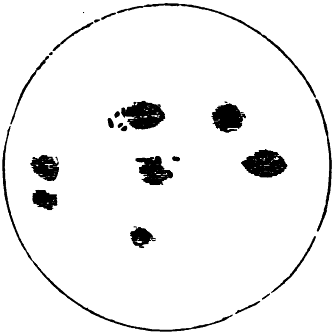


FIG. 15.—SUN SPOTS.

When the solar spots were more closely observed it was found that they were not of uniform darkness, but that they consisted of a black nucleus, surrounded by a dusky penumbra, the latter being usually much larger than the former, and often one penumbra surrounding two or more nuclei, whilst occasionally a spot was seen to consist of a penumbra but no nucleus. In size they were found to be very variable, ranging in diameter from a few seconds to one or two minutes of arc, the diameter of the sun being only thirty-two minutes. In number they were very variable, sometimes only two or three being visible, while at other times several dozen could be detected, and they seemed to have a tendency to appear in groups. Fig. 15 shows a drawing of the sun covered with a great number of spots, as they appeared to the early observers, and where the size of the spots is exaggerated and the drawing very rough; and fig. 16 shows a similar drawing of a group of spots on a larger scale, and made with a higher power, but as coarsely delineated as before. Later we shall have an opportunity of comparing them with modern drawings. It must be said that some of the earlier drawings are much better executed than these. Both Galileo and Scheiner remarked that the spots seemed as a rule confined to the equatorial regions of the sun, and to be within 30° from the solar equator.

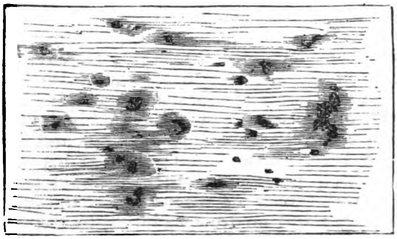


FIG. 16.—A GROUP OF SUN SPOTS.

The spots were not the only objects detected in the sun, but a number of long bright streaks were detected, and were called *faculæ*.

Bright markings on the sun.

These *faculæ* were brighter than the rest of the sun, and of very variable size, having a length of from two or three seconds to a minute or more, and are generally very much longer than they are broad. They are most frequent in the neighbourhood of the groups of spots, and are best seen when near the edge of the sun. The early observers also noticed that the entire surface of the sun seemed mottled or granulated in aspect, and that it was markedly brighter at the centre than at the edge.

The explanation of the origin of these black spots and bright markings was a constant theme for the early astronomers, but they were unable to arrive at a satisfactory explanation, although many wild hypotheses were advanced. Some, like Galileo, thought they were clouds; others, like Gassendi and La Hire, imagined they were opaque bodies floating on an igneous sea; whilst yet others thought they were volcanoes, and still a fourth school that they were apertures in a luminous atmosphere revealing the dark body of the sun. All of these hypotheses broke down, however, when carefully compared with the results of observation.

Transits of the inferior planets.

As the orbits in which Venus and Mercury revolve round the sun are smaller than the orbit of the earth, it is evident that they will pass at times between the sun and earth. If the orbit of the planet were in the same plane as the orbit of the earth, on every occasion that the planet passed between the earth and sun it would appear to pass over the sun as a black body; but as the plane of the orbit of the planet is inclined to the plane of the orbit of the earth, it is only when the planet is near one of its nodes when it is passing between the sun and earth that the planet will be seen to pass over the disc of the sun, and that there will occur a *transit*, as it is called. This has been already explained when we were considering the solar eclipses, which are transits of the moon across the sun.

Long before the invention of the telescope, astronomers had believed that they had seen transits of Mercury across the sun, though we now know that they must have taken a solar spot for the planet, because Mercury is so small that with the naked eye it cannot be seen on the sun. But in those early days of astronomy, Mercury was supposed to be about $1'$ in diameter, and Venus perhaps twice the size.

In 1629, Kepler having finished his tables of the motions of the planets, pointed out that there would be several transits of Mercury and one transit of Venus across the sun during the seventeenth century; and he drew attention to the fact that whereas transits of Mercury would not be uncommon, transits of Venus would be very rare. So rare, indeed, are these latter, that he stated that there would be only one during the seventeenth century, and only two during the eighteenth century. Finally, he predicted that both Mercury and Venus would cross the sun in 1631, the former on November 7th and the latter on December 6th.

Gassendi made arrangements to watch for these phenomena at Paris; and so that he should not miss them through errors in the tables of the motions of the planets, he determined to commence his watch two days before the time predicted by Kepler. To observe the phenomena he admitted the solar light into a dark room by a small aperture in its shutter, and obtained in this manner an image of the sun projected on a white screen. On the 5th of November he was disappointed, for it rained all day; and on the 6th he was no more fortunate, for though it did not rain, the sky was covered with clouds. This was not promising. Fortunately, on the 7th, the day which Kepler had predicted that the transit would occur, the sky turned out more promising, for though it was cloudy the clouds were broken. At about eight in the morning the sun commenced to break through the clouds, and by nine he obtained a distinct image of the solar disc. He examined it carefully, and saw a small black spot near the bottom, but no Mercury. However, he marked the position of this spot on the screen, because he thought it might prove useful, and if the planet in its transit passed near the spot, it might be used for finding the solar parallax. Later on he again had an opportunity of seeing the sun free from clouds, and still no Mercury; but to his astonishment the small black spot seemed to have moved. It seemed very strange; and, after very carefully marking its place, he was wondering how he could have made such a mistake in his previous observation, when the sun again came out. To his amazement, the spot had moved still farther. There could be no doubt now—no solar spot could move like that—the spot must be a planet in transit: it must be Mercury. He aroused himself instantly, and set to work to make accurate observations of its path, and signalled to his assistant, who was in another room, to make observations of the height of the sun, by which to fix the time. Unfortunately his assistant had not the same faith in Kepler's predictions as his master, and had gone away, thinking no transit would now be seen. He was sent for, and after some delay arrived in haste and made the necessary observation, enabling Gassendi to fix 10 h. 28 m. A.M. as the time of the egress of the planet from the disc of the sun.

First transit of Mercury.

Gassendi found from his observation that the transit occurred 4 h. 49 m. 30 s. before the time predicted by Kepler, and that instead of Mercury being about 60″ in diameter, it was not more than 20″ in diameter.

Although Gassendi was the only astronomer who was successful in seeing this transit of Mercury, he was not the only astronomer who watched for it; both Schickhardt and Mostling watched in Germany, using a method similar to that employed by Gassendi, but making use of a larger aperture. The planet being so small, it was not seen by them, as they employed too large an aperture to see so small a body.

Gassendi now prepared to observe the transit of Venus which Kepler had predicted would occur on the 6th December. It was stated that the planet would enter on the solar disc at a little before sunset. If, therefore, the tables were a little too early, the transit would not commence until after sunset, and so would not be visible in Europe. But Gassendi had found that Kepler's tables of Mercury were late, and hoped that his tables of Venus might also be late, so that the latter planet would begin its transit some time before sunset; and therefore made arrangements similar to those he had found successful for the transit of Mercury.

On December 4th and 5th a violent storm prevented any observations; and on the 6th he was also disappointed, for he only obtained occasional glimpses of the sun, and saw no trace of Venus, though this was the day of Kepler's prediction. He felt, therefore, that he had lost the transit, unless Kepler's tables were much too early. On the 7th the sky was clear, and he watched for the planet, but entirely without success. He had missed it. Kepler's tables were a little early, and the transit had taken place during the night between the 6th and 7th.

Kepler had announced that the next transit of Venus to that of 1631 would be in 1761, or 130 years later, so astronomers felt that for a century and a third they must postpone all hopes of observing a transit of Venus across the sun.

In 1639 there was living at Hoole, a small Lancashire village not far from Liverpool, a young clergyman of the name of Jeremiah Horrocks, who was endowed with great genius, and proved himself a great astronomer, though his early death in 1641, in his twenty-second year, cut short his career.

First transit of Venus.

Horrocks had been carefully comparing the position assigned to the planets by Kepler's tables with their observed positions, and he found that they were moderately accurate, though often more than 15′ out—not a large quantity in the state of astronomy then. He found that Kepler's tables made the planet pass close under the sun on November 24, 1639, old style (December 4, new style). Horrocks had also compared with the observations some tables constructed by the Belgian astronomer Landsberg, which had been much vaunted by their author, but to his disgust he found them very far inferior in accuracy to the tables of Kepler. Horrocks was struck, however, by the fact that, according to Landsberg, on November 24, 1639, the planet Venus would cross over the upper portion of the solar disc, so that a transit would occur. He knew these tables of Landsberg were very often wrong, but he had found that the true place of the planet was usually between the places predicted by Kepler and Landsberg; so that he thought it was just possible that though the tables of Landsberg might place the planet very much too far north, yet Kepler's tables might place it a little too far south, so that the planet might just cross the southern portion of the sun, instead of going a little south of it, as Kepler predicted. He carefully compared the tables with the observed place of the planet, and convinced himself that this would probably be the case. He therefore wrote to a young brother astronomer named Crabtree, who resided near Manchester, and requested him to watch for the transit.

The 24th of November was a fine day, though many clouds covered the sun at intervals, and Horrocks watched the sun from the time of its rising. No planet appeared by the time he had to go to church, it being a Sunday, whilst the sky became overcast with clouds. On his return, at a little after three, there seemed little chance of his obtaining a view of Venus, for the sky was still cloudy and the sun set before four. Fortunately, at about a little before the quarter, he saw a break in the clouds, which gradually approached the sun, and soon that luminary shone brightly through the gap. To his joy he saw a perfectly round large black spot just within the sun: it was the planet Venus. He watched it gradually moving across the sun for half an hour, when the setting of the latter put a stop to further observations, the planet having moved in that interval about twice its own diameter. Its diameter he estimated at about 1′ 12″, which was much smaller than had been commonly supposed. Crabtree, at Broughton, near Manchester, was also successful in seeing the planet, the sun bursting through the clouds just before sunset. He estimated the diameter of the planet at 1′ 3″.

Thus, the first transit of Venus known to have been observed was seen by two amateur astronomers in the north of England, and by them only. It seems strange that no other astronomer should have been on the watch for the phenomenon, which could have been seen well in France; for though it is true that Kepler had predicted that a transit would not occur, yet Landsberg's tables were not without reputation at this time, and they actually predicted a transit.

Horrocks suggested several important improvements in the theory of astronomy,* but his early death prevented these being made public, so that they were lost to science, being only made known many years subsequently. These improvements show the great loss that was experienced by astronomy in the death of Horrocks, and render it probable that, had he lived, many of the great astronomical discoveries would have been achieved a century before their actual date.

Subsequently a transit of Mercury was observed on November 3, 1651, by Shakerley, a young English astronomer, who had proceeded to Sürat, in India, for the express purpose of seeing it—thus inaugurating the long series of expeditions to secure astronomical observations. Another was seen on May 3, 1661, by a number of observers, including Huygens, Street, and Mercator, in London, and Hevelius in Dantzic; and since then they have been repeatedly observed, occurring every few years. Hevelius made the diameter of Mercury only 12″, which is close to its true value.

The transits of Mercury, it is to be observed, are much more frequent than those of Venus, in consequence of the former planet being nearer the sun, and having thus a narrower orbit and a shorter year; but they are not available for the determination of the solar parallax or distance of the sun, like those of the planet Venus, as we shall see.

---

* One of these was showing how the inequality in the moon's motion, termed the evection, could be explained by supposing the eccentricity of the moon's elliptical orbit to be variable, and the moon's perigee to be subject to a slight swaying from its mean position—thus anticipating Newton's famous discovery.

CHAPTER III.

IMPROVED ASTRONOMICAL INSTRUMENTS.

Astronomical Clocks—Application of the Pendulum—Use of improved Telescopes—Introduction of Telescopic Sight—Graduated instruments—Introduction of the Vernier—Invention of the Micrometer—Right Ascension of a Star—Equinox—Declination of a Star—Astronomical Quadrant—Regulation of clocks by Transits of Stars—Invention of the Transit Instrument—Use of the Transit.

DURING the third quarter of the seventeenth century, or from 1650 to 1675, many improvements were introduced into practical astronomy, contributing much to its progress and enabling much more accurate observations to be made. It will be well to notice the more important of these.

Astronomical clocks.

First of all comes the invention of the astronomical clock, the most precious gift to practical astronomy, and one which has done more than any other to facilitate its grand achievements. Clocks had been known for centuries, but they were so untrustworthy that they were quite unfit for the delicate needs of astronomy; astronomy requires seconds, while these instruments would not give minutes. Galileo discovered that the beats or swings of a pendulum were always made in sensibly exactly equal times, so that if a clock were constructed to register the number of beats which had been made by a pendulum, it would give an accurate clock. He tried to make a clock on this principle; but without success, for he could not keep it going. When he set the pendulum going the clock started well enough, but the pendulum was gradually stopped by the work performed by it in moving the wheels. Galileo and his contemporaries gave up in despair the idea of constructing a clock of this nature. Gassendi, Bullialdus, and others, made use of the pendulum to measure short intervals of time, by actually counting its vibrations from a moment at which the correct time had been ascertained. To find out the exact time at any moment, they had to observe at that instant the altitude of the sun or a star above the horizon, and then calculate at what time it was that the sun or star had that altitude. This was a long operation, and they could not be sure of the time to less than half a minute.

In 1656, Huygens, the grand genius whose name has been already mentioned on several occasions as a discoverer, added one more to the long list of his contributions to astronomy. Thinking over the imperfections of the ordinary clocks which were kept going by a weight slowly falling, and pondering over the failures of Galileo to make a good clock by the swing of a pendulum, something like the following thought occurred to him:—"Here we have an ordinary clock which is driven and regulated by a weight, and will go for a century, but is so badly regulated that it won't keep true time; and there we have Galileo's clock, which is driven and regulated by a pendulum, and keeps correct time, but is so badly driven that it won't go for more than an hour: suppose I put the two together, and drive the clock by the weight as long as I want, and regulate it as correctly as

I desire by means of a pendulum." He considered the matter. and it seemed feasible enough; so after sundry experiments he constructed a clock which had its wheelwork driven by a falling weight, and regulated by a pendulum which only allowed it to move forward by one tooth of a toothed wheel once during each swing of the pendulum. In this way the pendulum had nothing to do but to swing, and let the wheels of the clock register the number of swings which had been made, while the weight kept the clock going and the pendulum swinging. Huygens' clock was a grand success, and quickly spread everywhere. By regulating it once or twice a day by means of the altitudes of several stars, it gave the correct time at any instant to within three or four seconds.

Application of the pendulum.

During this period, 1650-75, the ordinary or Keplerian telescope came into universal use, and observers were no longer restricted to magnifying powers of 30 or 40 diameters, but were able to use powers three or four times as great. Astronomers, however, still determined the place of the stars in the heavens by the naked eye. Their instruments were provided with two little spikes or two little plates with small holes in them, and they used these like "sights" on a modern rifle to direct the instrument to the object. They could never be sure of the place of a star by less than 5′ or 10′, because to the naked eye that space looked so small. In 1665, Hooke and Sir C. Wren constructed astronomical instruments in which a telescope was employed to direct them to the star, instead of using naked eye "sights." Picard, a famous French observer, was the first to adapt the telescope to regular astronomical instruments. The centre of the field of view of the telescope was marked by a combination of very thin wires, and when pointing the telescope at the star or other celestial object the instrument was moved until the star was brought into the centre of the field of view. This was found to be an immense improvement, for as the telescope made the part of the heavens it was pointed at look 60 to 70 times larger, and the star look smaller than with the naked eye, it was found easy to point the telescope, and with it the instrument, with a hundred times greater accuracy. Instead, therefore, of being uncertain by 5′ whether the instrument was properly directed at the star, they could feel quite certain to two or three seconds.

Use of improved telescopes.

Introduction of telescopic sight.

By this grand improvement, whilst observations were rendered very much more accurate, it was found that the difficulty in determining the places of the celestial bodies was entirely changed. It was no longer that they could not properly direct their instruments, but that they were not quite sure at what place they were directing them. When they had properly pointed the instrument at the planet or star —and this was no longer difficult—astronomers wanted to know how many degrees, minutes, and seconds it was from the zenith, or from the north pole, or some other point. To ascertain this, each instrument had a circle or part of a circle divided into degrees and minutes by very fine marks called *divisions*. A pointer fixed to the telescope moved along this arc of a circle, or graduated arc as it is termed, and showed how many degrees and minutes the telescope had moved over, as it was moved from one point to the other. Thus, suppose the telescope to be pointed directly overhead, or to the zenith, and that the pointer marked 51° 38′, and that it was then moved to point to a bright star, and the pointer was at the division indicating 30° 11′, we should know that the telescope had moved over 21° 27′, or that the zenith distance of the star was 21° 27′. This method was very simple. Now, suppose our instrument to have a graduated circle twelve feet in diameter, or a portion of such a circle, it would be a very large instrument, and it would not be very easy to divide the circle with accuracy. But if one degree (say the mark showing 21°) was put a little out of its proper place—a little too far on (say a tenth of an inch wrong), then, instead of being in its proper place, it would be in the place where 21° 5′ ought to be, and all our observations would be 5′ wrong—a large quantity. It was therefore the difficulty of dividing the circles, or as it was called graduating the instruments, which now began to trouble astronomers, and they had to take great care to get their instruments properly graduated.

Graduated instruments.

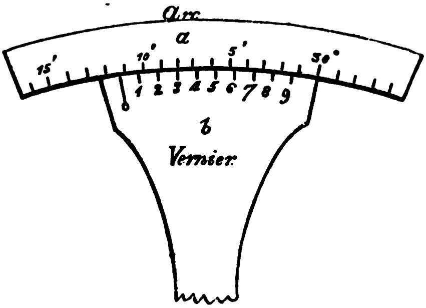


FIG. 17.—THE VERNIER.

They very soon found still another difficulty—that was in graduating their instruments to fine enough divisions. They could point their instruments to within several seconds, and they wanted to be able to read their instruments to five or ten seconds—that is to say, to tell from the graduated arc not only how many degrees and minutes the telescope had been moved, but how many seconds as well, or at least whether it was 10′ 10″ or 10′ 15″. But on an instrument with a graduated circle twelve feet in diameter, the divisions indicating the minutes were separated from each other by only one-fiftieth of an inch, so that there was no room for the markings indicating the seconds. This difficulty was got over by making use of what is called the *Vernier*, named after its French inventor, Pierre Vernier. Fig. 17 shows the principle of the vernier, *a* representing the graduated arc of the instrument, and *b* the arc of the vernier, and this arc is divided into nine divisions, which occupy the same space as ten divisions of the graduated arc of the instrument. Now suppose the division marked 0 on the vernier

Introduction of the vernier.

corresponds exactly with one of the divisions of the arc of the instrument (say 30° 11′), then the exact position of the instrument will be given by that division, or will be 30° 11′. This will very seldom be the case; it will nearly always be found that the division 0 of the vernier does not correspond with any division on the arc of the instrument, but will be between two divisions, as shown in the figure, so that though more than 30° 11′, it is not 30° 12′. If this be so, see which of the other divisions on the vernier agrees exactly with a division of the arc of the instrument; in the figure it will be seen to be that marked 3. Then the true position of the instrument is $\frac{3}{10}$ of a minute past 30° 11′, or 30° 11′ 18″. The reason why this is so is easily seen by examining the figure, each division on the vernier gaining $\frac{1}{10}$ of a minute on the arc of the instrument. Every division of the arc, or 1′, can be therefore subdivided into ten parts; or, as it is commonly said, the vernier will read to 6″.

In practice verniers are constructed so that 59 divisions of the vernier correspond to 60 divisions of the arc (or *vice versâ*), and they read therefore to seconds if the arc be divided to minutes; so by this ingenious invention astronomers were able to make their instruments read to or indicate single seconds of arc. For some time, however, astronomers contented themselves with dividing their instruments to every 5′ and reading to every 5″, because they found it very difficult to properly graduate circles more finely.

Invention of the micrometer.

Before long astronomers experienced the want of an instrument for measuring small distances in the heavens, such as the diameters of the sun and planets, and the distance of stars from each other. This led to the invention of the *micrometer*. The original inventor of this instrument seems to have been Gascoigne, a Yorkshire gentleman, who constructed one in 1638; but his invention was not made known for many years after his death. Micrometers were introduced into astronomy by an independent discoverer, Auzout, a French astronomer who described his invention in a letter to the Royal Society in December 1666. The ordinary micrometer, or parallel-wire micrometer as it is called, consists of a pair of very thin wires (called wires, though generally made of silk fibre or spider's web) stretched on movable frames, strictly parallel to each other. These wires can be moved nearer together or farther apart by a very fine screw, which has a large head graduated into 100 parts. This instrument is placed so that the wires are in the focus of the eyepiece, and can be seen in the field of view of the telescope at the same time as the celestial body. By experiment it is ascertained how far ten turns of the screw will move the wires: suppose it is $8\frac{1}{3}$′ (or 500″), then one turn will correspond to 50″, and one-hundredth part of a turn to $\frac{1}{2}$″. Suppose then it is found that it requires the head of the screw to be moved 81 divisions to separate the wires by the same amount as the diameter of Jupiter—that is to say, so that if one wire is made to touch one edge of Jupiter the other wire will touch the other edge—then the diameter of Jupiter will be $81 \times \frac{1}{2}$″ or 40·5″.

It will be well before proceeding further to ascertain how astronomers are accustomed to point out the positions of the different objects in the heavens; so that by saying a star or planet is in Right Ascension so-and-so, and Declination so many degrees, or else in such and such longitude and latitude, its place in the heavens is at once fixed.

Right ascension of a star.

Suppose the heavens represented by a large globe, and that we are placed at the north pole of this globe, at P, fig. 18, so that the figure represents the northern hemisphere of the heavens, with the equator at the circumference. From geometry we know that any circle dividing the surface of a sphere into two equal halves is called a great circle, and both the equator and ecliptic are great circles of the heavenly sphere. Suppose the equator divided into 24 equal divisions, as shown in the figure, so that each division will contain 15° of the 360° in the entire circumference. Then astronomers call each of these divisions *one hour of right ascension*, and divide this hour into minutes and seconds just as if it were an hour of time. They call the great circles *a* P *a'*, *b* P *b'*, hour circles, and each one serves to mark out the space called one hour in the heavens, dividing the sphere into halves, and seen as straight lines. These hour circles are seen better as such in the second figure, which gives another view of the heavenly sphere.

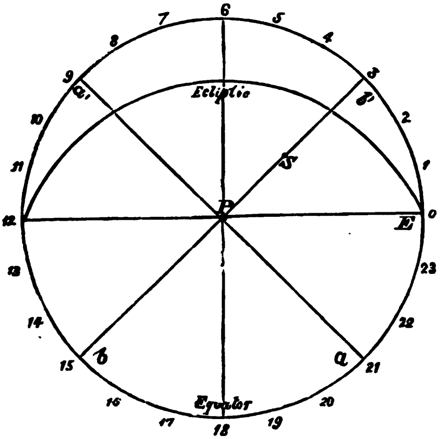


FIG. 18.

The reason why these circles and divisions are called hour circles and hours is very simple. It is because it takes exactly one hour for the earth to rotate on its axis through that amount, so that if at any time the stars at hour 6 are seen on the meridian, at one hour later the stars at hour 7 will be on the meridian. Now, astronomers count these hours from the point E, where the equator is crossed by the ecliptic as it passes from the southern to the northern hemisphere, and this point E they call the *vernal or spring equinox*. Let S be a star: we see it is on the great circle or hour circle which is marked 3, or the 3rd hour circle; then astronomers say that the right ascension of this star S is 3 hours, or the star is

Equinox.

in 3 hours of right ascension. This by itself is not sufficient to tell us the place of the star, for though we know it is on the hour circle P *b*, it does not tell us whereabouts on that hour circle. Astronomers therefore call the distance of the star from the equator the declination of the star, this declination being given in degrees, minutes and seconds of the circumference of the hour circle. In the figures the star is about 62½° from the equator, and towards the north pole, so that its position is said to be 62½° north declination. Sometimes instead of declination astronomers fix the position of the star by saying its distance from the north pole; thus they would say that the position of the star S was either 62½° north declination, or 27½° north polar distance. Astronomers sometimes fix the position of objects by their latitude and longitude, and in the earlier days of astronomy these were almost always used. The longitude of a star is merely its distance from the vernal equinox,

Declination of a star.

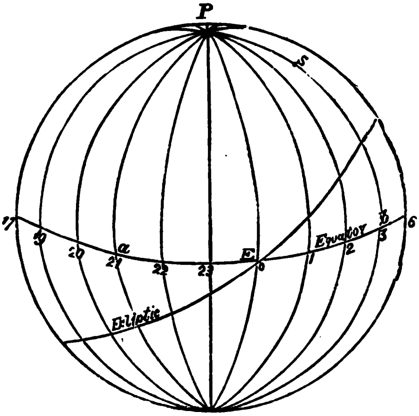


FIG. 19.

measured along the ecliptic instead of along the equator like the right ascension. The latitude is its distance measured along a great circle perpendicular to the ecliptic, instead of being measured along a great circle perpendicular to the equator like the hour circles on which the declinations are measured. The longitudes are not given in hours and minutes of time, like the right ascension, but merely in degrees and minutes of arc.

Occasionally astronomers fix the position of a body by its *altitude* and *azimuth*—its *altitude* being the height of the body in degrees, etc., above the horizon, and its *azimuth* its distance from the meridian in degrees, etc.; the horizon being supposed divided into degrees, etc., like the circumference of a circle. Thus, if fig. 19 was a plan of the observer's heavens, with the zenith at P and the meridian at P E, each of the divisions would represent 15° of azimuth, and the star S would be in azimuth 45°.

The early astronomers determined the position of the stars and planets by means of instruments containing graduated circles, one fixed in the plane of the equator and the other revolving on an axis parallel to the axis of the earth. They thus resembled in principle the modern equatorial, an instrument which will be subsequently described. The fixed circle showed the angular distance between any two bodies measured on the equator, or their difference in *right ascension*, and the movable circle showed the distance of a body from the equator, or its *declination*. It was very difficult to properly adjust these instruments, and almost impossible to keep them adjusted. To determine the time, they made use of a quadrant, and after the invention of the telescope they fitted a telescope to this quadrant.

Astronomical quadrant.

The astronomical quadrants were generally constructed after the manner of fig. 20, where we see a quadrant or quarter of a circle of wood or iron strengthened by cross-bars, and fitted with a telescope, whilst its edge is graduated into portions of a degree, and carrying a vernier. These instruments were usually from five to nine feet in radius, and were mounted on a pillar so as to be exactly perpendicular. They determined the time by observing the altitude of a star, and then by calculation finding out at what time the star would have the observed altitude.

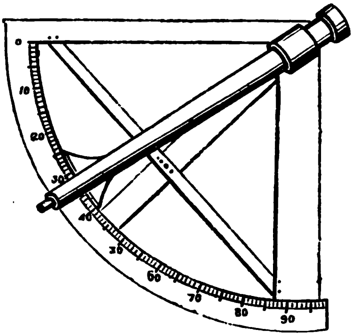


FIG. 20.—ASTRONOMICAL QUADRANT.

The invention of the astronomical clock enabled astronomers to much simplify their method of observation. Instead of mounting their quadrant on a pillar, they fixed it against a wall built due north and south, so that the quadrant was fixed in the plane of the meridian. They then observed the altitude of a star when it crossed the meridian, and noted the exact time when the star crossed the meridian—which would be shown by the moment it crossed a wire put in the centre of the field of view of the telescope. By subtracting the complement of the latitude of the observatory from the altitude they obtained the declination. Thus Greenwich was determined by Flamsteed to be in latitude 51° 28′ 10″, and the complement of this angle is 38° 31′ 50″. Thus a star whose observed altitude was 61° 15′ 20″ would be in declination + 22° 43′ 30″. Next, the difference in time between the passage of any two stars across the meridian is equal to the difference in right ascension between them. Thus, if a star whose right ascension was known to be 5 hours 7 minutes 21 seconds passed the meridian at 7 hours 11 minutes 28 seconds, and another star passed the meridian at 9 hours 25 minutes 51 seconds, the difference between these two (2 hours 14 minutes 23 seconds), added to the right ascension of the first star, would be equal to 7 hours 21 minutes 44 seconds, which would be the right ascension of the second star. It was only necessary, therefore, to know the exact right ascension of a few bright stars to be able to find the right ascension of all the others.

By this method observations of the positions of the heavenly bodies were made very much easier, it being only necessary to have a good clock. To avoid errors due to imperfections in the clocks, many observatories had more than one—Delisle being provided with seven or eight—and the mean of all was taken. It was soon found easy, however, to regulate the clock by the observation of the sun, or of stars whose right ascension was known. Thus, when the right ascension of a bright star had been fixed by several hundred observations, the errors of the different clocks might be reasonably expected to have destroyed each other, because if the clock were a little too fast on one day it would be a little too slow on another, and these would counterbalance one another, and the right ascension given by the mean of all the observations might be depended on to be true within a second of time. Astronomers could calculate, therefore, the exact time when this bright star ought to cross the meridian. Say it was 7 hours 50 minutes 30 seconds ; then if they observed it to cross at 7 hours 50 minutes 45 seconds, they would know that their clock was 15 seconds fast. Occasionally they would correct the clock by observing the altitude of the sun or a star at some fixed time by the clock—say 8 hours—and then calculating the time at which the sun should have that altitude, and if this proved to be 7 hours 59 minutes 37 seconds they would know that their clock was 23 seconds fast. After a time they found this second method was much less exact than the first, and they abandoned it.

Regulation of clocks by the transit of a star across the meridian.

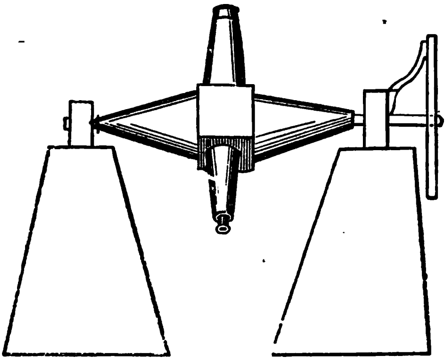


FIG. 21.—TRANSIT INSTRUMENT.

They found subsequently that their large quadrants fixed to a wall, or mural quadrants as they were termed, gradually warped out of their proper position, and they also found it very difficult to ascertain whether they were properly adjusted. These things interfered much with the proper determination of the right ascension of stars, though they did not interfere much with the determination of the declination; for to determine the last it was not essential that the instrument should be exactly adjusted to the meridian.

Invention of the transit instrument.

Use of the transit.

Roemer, a very distinguished Danish astronomer, invented a new instrument to obviate these errors, and called it a *Transit instrument.* It was constructed after the method shown by fig. 21. It consists of a telescope mounted in a strong tube, consisting of two conical ends, fastened to a cube in the centre, the cube being mounted on a long axis made in the shape of two cones to prevent its bending. The pivots at the end of this axis are supported on two metal bearings, firmly fixed on two stone pillars, and at one end it carries a graduated circle. The whole instrument is placed exactly on the meridian, and the axis made perfectly horizontal, so that as the telescope turns on the pivots at the ends of the axis it will move in the great circle called the meridian. The eyepiece is fitted with a series of fine wires, as shown in fig. 22, consisting of five vertical and two horizontal wires, the central vertical wire being placed exactly in the place of the meridian, and the others at equal intervals on each side. When an observation is made the astronomer moves the telescope until the star appears to move into sight from the right hand, between the two horizontal wires, and he times exactly the moment it crosses each wire. Suppose it crosses the first wire at 7 hours 38 minutes 7 seconds, the next at 18 seconds, the next or middle wire at 28 seconds, the next at 39 seconds, and the last at 49 seconds. Adding all these seconds together and dividing by 5, we get 28·2 seconds for the true time it crosses the central wire, or 7 hours 38 minutes 28·2 seconds for the time of transit. The reason of having the five wires is so that any slight uncertainty in the time the stars crossed a single wire may be removed by taking the mean of the time it crosses the five wires; because if a little error in one direction be made at one wire, it is probable it will be counterbalanced by an error in the opposite direction at another wire.

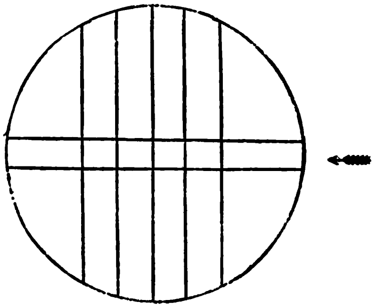


FIG. 22.—THE EYEPIECE OF THE TRANSIT INSTRUMENT.

It was found much easier to adjust the transit instrument than the ponderous mural quadrants, and the right ascensions which were obtained by means of the transit instrument were found to be far more accurate. It was not long, therefore, before the transit instrument came into general use, and the mural quadrant was confined to observing the declinations. Towards the end of the following century the quadrant or quarter of a circle was replaced by a complete circle.

The complete outfit of an observatory during the later part of the seventeenth and in the eighteenth century consisted of a movable quadrant, a mural quadrant or circle, a transit instrument, one or more good clocks, and several telescopes.

CHAPTER IV.

FURTHER TELESCOPIC DISCOVERIES.

Cassini's Discoveries—Solar Parallax—Diameter of the Earth—Discovery of the Transit of Jupiter's Satellites—Rotation of Mars—Discovery of New Satellites to Saturn—Strange Variations in Brightness—Duplicity of Saturn's Ring—Discovery of Additional Satellites to Saturn—Size of the Sun, Moon, and Planets—Discovery of the Existence of Nebulæ.

OWING to the improvements which had been introduced into astronomical instruments, the principal discoveries which were made in the latter portion of the seventeenth century were owing to astronomers being now able to employ more powerful telescopes, and to make delicate measurements with the aid of the micrometer.

Cassini's discoveries.

During this period the principal contributors to this branch of astronomy were Cassini, Hooke, and Hevelius, but principally the first. Born in Italy, J. D. Cassini was one of the most energetic and successful observers who ever lived, and to his labours astronomy is indebted for the first accurate information about the physical condition of the different members of the solar system; and we shall see his name connected with many of the most brilliant discoveries in this department of astronomy.

Solar parallax.

Little that was new was learnt about the sun, although drawings were made of the appearance of the faculæ and sun spots; but it was not until the end of the following century that any real progress was made in our knowledge of the physical condition of the sun. Some further information was learnt respecting its distance from the earth. We have already seen how astronomers were able to ascertain the approximate distance of the different planets from the sun, if the distance of the earth were taken as unity. And we have also seen how the famous laws of Kepler enable one to tell with accuracy the distances of every planet from the sun, if once the distance of one planet be known. We have also learnt how astronomers found out the distance of the moon by its parallax, or the apparent alteration in its place amongst the stars when it is seen from different sides of the earth. Now, Kepler's theory of the planets showed that Mars approached the earth until only about one-third as far off as the sun; and astronomers thought that this might be close enough for them to be able to measure the parallax by comparing the place of the planet with some known star. Richer, a French astronomer, proceeded in 1672 to Cayenne in South America (not in Africa, as commonly stated), to observe Mars; and Cassini, Römer and Picard observed the planet in France. When they came to compare their observations they found that the parallax or alteration in the place of the planet was so small that they could not determine its value with sufficient accuracy. It was not greater than 25″, and it could not be less than 15″, or they would not have been able to detect it at all, whereas there was obviously some difference. Cassini, on taking everything into consideration, fixed on the value 21″ as the parallax of Mars when seen from opposite sides of the earth, and from that he calculated that the parallax of the sun was 9·5″, or its distance 86 million miles. It was easy then by Kepler's laws to ascertain the distances of the other planets from the sun. Mercury was 34 million miles distant, Venus was 62 million, Mars was 121 million, Jupiter 447 million, and Saturn 818 million miles distant from the sun.

Cassini and La Hire, his colleague at the Royal Observatory at Paris, both carefully mapped the surface of the moon, but their new charts were little, if any way, superior to those of their predecessors Hevelius and Riccioli. As in the case of the sun, a century was to elapse before any real advance was made in our knowledge of the physical condition of our satellite.

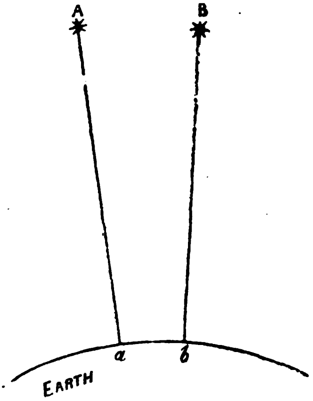


FIG. 23.—MEASURING AN ARC OF THE MERIDIAN.

Diameter of the earth.

It is essential for the proper study of astronomy that astronomers should know the correct value of the diameter of the earth. At this period it was commonly supposed that the earth was about 21,600 miles in circumference, or 3440 miles in radius. Astronomers however, knew better, and used the more correct value 3810 miles, which had been deduced by Snellius in 1615. The method by which the diameter of the earth is found out is very simple in theory, though there are difficulties in practice; and consists in measuring an arc of the meridian, as it is called. An observer at the point *a* on the earth (fig. 23) chooses a star (A) which passes exactly overhead, and another (B), which is a little to the south; in the figure it is about 10° south. He then moves south along the surface of the earth until he comes to a spot like *b*, where the star B passes exactly overhead, and the star A passes about 10° to the north. He then knows that, as the earth is a sphere, he has moved exactly 10° over the surface of the earth, and the distance he has travelled is the length of 10° of the earth's circumference. He measures the length in miles of the distance he has moved due south—say it is 665 miles—and he knows that 10° of the earth's circumference measures 665 miles, or one degree measures 66½ miles. Geometry teaches him that the radius of the earth is equal to $57\frac{3}{11}$ of the length of one degree, or in the case supposed 3810 miles.

Several years after the determination of Snellius, his pupil Muschenbrock, another Dutch astronomer, measured the length of an arc of the meridian in the Netherlands, and using more powerful instruments than Snellius, found the radius of the earth to be 3960 miles. In 1635, Norwood, an English astronomer, measured the arc of the meridian between London and York, and found the diameter of the earth to be 3982 miles. The most exactly determined value of this period was, however, that of Picard, the French astronomer, who found the diameter to be 3959 miles. We now know the radius or semi-diameter is 3962 miles. The popularly current value of 3440 miles was generally used by philosophers until near the close of the seventeenth century, when Picard's value displaced it; and we shall see how Newton was misled by it, though we may wonder why he did not take the more correct results of Snellius or Norwood, which were even then known to be more accurate.

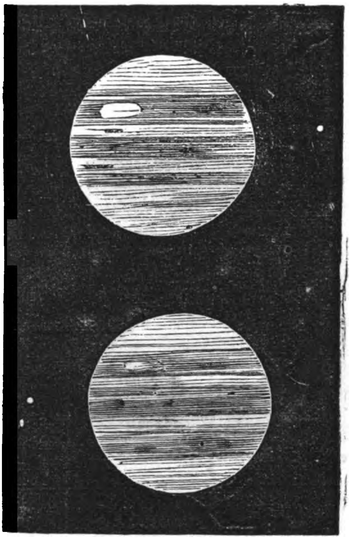


FIG. 24.—EARLY DRAWINGS OF JUPITER.

In 1664, whilst residing in Italy, J. D. Cassini obtained a very fine telescope from the most celebrated maker of the time—Campani of Rome: it was 37 feet in length, had an aperture of 3½ inches, and magnified 130 times. With this telescope he assiduously studied the planet Jupiter. The planet he saw was crossed by three dusky belts running parallel to the orbits of the satellites. On these belts from time to time he saw both dusky and white spots. They none of them appeared to remain visible for more than a few hours, and even the belts seemed to alter in appearance. In July 1665 he discovered a large white spot on the lower edge of the uppermost or southern belt, and on two or three subsequent days he saw the same spot, but it appeared to have changed its position. One day it appeared indistinct and close to the eastern edge of the planet, and watching it attentively he saw it slowly approach the centre of the planet, when it looked large and distinct: soon after it had passed the centre, and gradually approached the west border, until it was lost near the edge of the planet. In four hours it seemed to have moved over two-fifths of the circumference of the planet. Cassini felt convinced, from what he had seen, that it was fixed to the planet, which was rotating on its axis like the earth, only so much faster that it only required ten hours for a complete rotation. Two days afterwards the spot was again seen by him, only it was one hour later in reaching the centre of the planet; in 49 hours, therefore, the planet had made five rotations, or took 9 h. 50 m. to rotate on its axis. Cassini continued his observations, and found that in almost exactly 12 days the spot on the planet had come back to the same place as before. It must have made 29 revolutions, each revolution taking 9 h. 56 m. This was a brilliant discovery, for in the revolution of Jupiter on its axis was a striking confirmation of the fact of the revolution of the earth on its axis.

Cassini continued his observations, and before long discovered a very minute black spot on the planet, much smaller than those dusky spots he had seen. This spot moved quickly across the planet from extreme edge to edge, and did not grow indistinct and disappear insensibly near the edge. Soon after he discovered other similar black spots, some of which seemed to take only a little over two hours to cross, and others required nearly five hours; so that in most cases they moved far quicker than could be accounted for by the rotation of the planet, and therefore could not be black spots fixed on the surface of the planet itself.

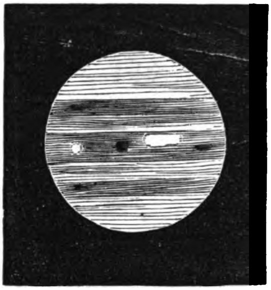


FIG. 25.—SATELLITE IN TRANSIT.

Cassini discovers transit of Jupiter's satellites.

Cassini soon found that these spots were only to be seen when one of the satellites was in or near its time of transit across the planet, and that they moved at about the same rate as the satellite itself. He immediately suspected that they were the shadows cast by the satellites; so that he had seen the phenomena whose existence had been predicted by Galileo, but which his predecessors had been unable to see owing to their telescopes not being powerful enough. Later he was successful in seeing some of the satellites themselves in transit over the disc of Jupiter, when they appeared as minute brighter spots on the dusky belts of the planet. Having discovered the cause of these spots, he was able to predict the time when they would be visible; and these predictions being verified by observation, it established the correctness of his explanation of their nature.

Continuing his observations, Cassini found that the satellites did not move, as had been supposed, in the same plane as the orbit of the planet, but in a plane inclined to it by 2° 55′, and that the equator and the belts of the planet were also inclined to the orbit of the planet by the same amount; so that, as in the case of the earth, the axis of Jupiter was inclined to its orbit. These discoveries he embodied in a series of tables of the satellites, from which could be obtained their position and the times of their eclipses and transits.

Next turning his telescope on Mars, he discovered a number of greyish spots on the disc of that planet. He found that every day these spots seemed to reappear about three-quarters of an hour later, and from a comparison of his drawings of the planet was able to fix on 24 h. 40 m. as the time of its complete rotation on its axis. This value has been found by subsequent observations to be very nearly correct. On examining Venus, he also suspected that its bright disc contained some very faint markings which changed in position, and seemed to indicate that the planet revolved on its axis once in 23 hours. He could not feel sure of this, for, like all the earlier astronomers, he found Venus a very difficult object to observe.

Rotation of Mars.

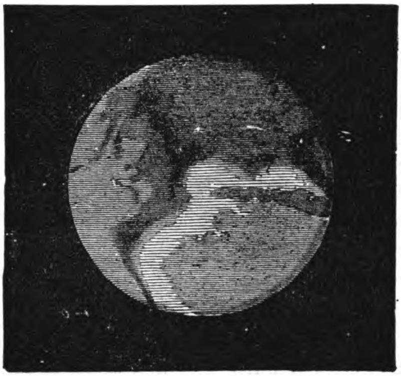


FIG. 26.—MARS.

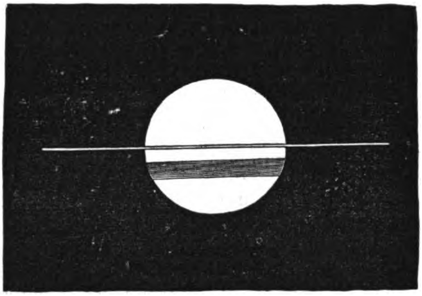


FIG. 27.—SATURN.

In 1669, on Louis XIV. founding a Royal Observatory at Paris, Dominic Cassini was appointed its head, and leaving Italy took up his residence in France, and energetically resumed his observations of the physical aspects of the planets. On October 25th, 1671, Cassini was watching the planet Saturn with a telescope 17 feet in length, with

Discovery of new satellites to Saturn.

Strange variations in brightness.

an aperture of 3 inches and a power of about 100—one of the best instruments in the equipment of the Royal Observatory. The ring of Saturn was then presented almost edgeways to the earth, so that it looked like a narrow line of light; and Cassini noticed a small star to the west of the planet, and nearly in the same line as the ring. On the following evening he was surprised to find that though the planet seemed to have moved a considerable distance amongst the stars, this particular star seemed to have accompanied it. Accordingly he closely watched during the following night, and found that it moved with the planet, and slowly revolved round it in about eighty days: it was a new satellite to Saturn. Towards the end of the year Cassini lost sight of the new satellite, and could not see it, although it was looked for most perseveringly. He therefore procured a more powerful telescope—one of 34 feet focus, with an aperture of nearly 4 inches, and a power 130—and resumed his watch for the satellite, but still without success. On the 13th December, 1672, he suddenly rediscovered it, and continued to watch it until near the end of the month, when it again disappeared and could not be found. On the 23rd December, 1672, Cassini saw a star in the place where the missing satellite ought to be, and thought he had again rediscovered it, but on the subsequent day he found it had moved much farther than it could have done had it been the missing satellite; yet it was certainly not moving like a star. The suspicion shot across his mind that he might have been so fortunate as to have discovered yet a third satellite. Unless his first observation was imperfect, it seemed to him that this must be so, for no star could have moved like this object. The observations of the next two or three days settled the matter: it was a new satellite, and one moving round the planet in about four and a half days. Later, Cassini was successful in rediscovering the missing satellite, and he found that it periodically disappeared. Whilst moving in the western half of its orbit round Saturn the satellite was bright and distinct, but during the six weeks it was moving in the eastern half of its orbit it remained invisible. The satellite first discovered by Cassini is now called Iapetus, and that afterwards seen is called Rhea, whilst the satellite discovered by Huygens is called Titan. All these satellites moved very nearly in the same plane as the ring, which, according to Picard, is inclined at an angle of 31° to the ecliptic.

Duplicity of Saturn's ring.

Whilst observing Saturn in 1675 Cassini discovered that the ring of that planet is divided into two by a black line, so that it appears to be composed of two concentric rings, and not one. This discovery excited much interest, and was soon confirmed. He had, however, been anticipated in his discovery by William Ball, a Devonshire gentleman, who, observing Saturn on October 13th, 1665, with a 38-feet telescope, perceived that its ring was nearly double. But, as in many similar instances, the discovery having been made by a comparatively unknown astronomer, it did not excite any attention, and was soon forgotten. This division in the ring of Saturn is called Ball's division, after its original discoverer.

In 1684, when the ring of Saturn was again turned edgeways towards the earth, Cassini scrutinised the planet with great care to see if there were yet other satellites. He made use of telescopes of great power, and having lengths of 100 and 136 feet respectively, with apertures of about six inches, and magnifying over 200 times. His perseverance was rewarded by the discovery of two more satellites, both of them much closer to the planet than any of the three previously known. One of these is now known as *Dione*, and revolves round the planet in 2 d. 18 h.; and the other is called *Tethys*, and requires only 1 d. 21¼ h. to revolve round the planet. In commemoration of these brilliant discoveries Louis XIV. had a medal struck bearing the inscription, "Saturni satellites primum cogniti."

Discovery of additional satellites to Saturn.

The invention of the micrometer enabled astronomers to deduce the apparent diameter of the celestial bodies. The sun was found to have a diameter of rather more than half a degree, and to vary slightly with the variations in the distance of the earth from the sun, but its average diameter was fixed at 32′ 10″. The diameter of the moon was found to vary between 29½′ and 33½′ according to its distance from the earth, its mean diameter being 31′ 20″. From its transit across the sun, Hevelius found that the mean diameter of Mercury was 6″. Cassini determined the mean diameter of Venus to be 18″, but when it was near the earth its diameter increased to over 1′, rendering it apparently the largest of all the planets. The distance of Mars from the earth being extremely variable, its diameter was found to vary between 5″ and 30″, its mean diameter being 7″. The larger planets varied little in apparent size, the mean diameter of Jupiter being 40″, and of Saturn 20″, though the ring of this last was 45″ in diameter. From these measures and Cassini's value for the distance of the sun—namely 86 millions of miles—it followed that the diameter of the sun was 800,000 miles, or more than one hundred times that of the earth, and its volume more than a million times as great. The moon was found to have a diameter of 2,180 miles, or to be in volume only one-fiftieth of that of the earth. Mercury was found to be but little bigger than the moon, and Venus to be almost exactly the same size as the earth. Mars was smaller, having

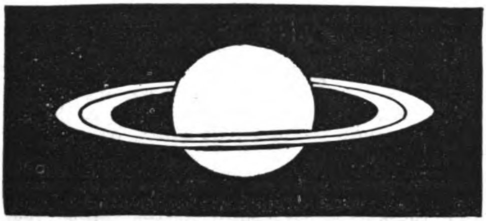


FIG. 28.—SATURN, AND HIS RINGS.

Size of the sun, moon, and planets.

a diameter of about 4,700 miles, or only three-fifths of the diameter of the earth, so that it would have a volume of about one-fifth. Jupiter had a diameter of 87,000 miles, or twelve times as great as the earth, so that this giant planet was in volume nearly two thousand times greater than our planet. Saturn was slightly smaller, the diameter of the planet being only 79,000 miles, but its ring was nearly 200,000 miles across. We shall see subsequently that these values were not very far out, and they enable a good idea to be formed of the relative dimensions of the different bodies of the solar system.

Discovery of the existence of nebulæ.

When the heavens were studied with more perfect telescopes than those employed by Galileo, it began to be discovered that the heavens contained other objects than the stars. Thus in 1656 Huygens discovered an astonishing feature in a star in the constellation called *Orion*—a star which had been designated θ by Bäyer. It appeared to be fixed in the midst of a faint filmy cloud of light, much as if it were surrounded by immense masses of faint luminous gas, whilst the surrounding sky was intensely black. Huygens had discovered, in fact, the celebrated Nebula of Orion. Astronomers had long been aware of the existence in the heavens of nebulous patches of faint light, much like isolated patches of the Milky Way; but when these were examined with the telescope they were seen to be groups of closely packed very faint stars, or, as they are called, "star clusters." One of these existed in the constellation *Cancer*, and was called *Præserpe*; another existed in the constellation *Perseus*,—in what was then known as the sword-handle in *Perseus*,—and a third near *Leo*. But this object was of a very different nature, because when seen in the telescope, instead of being seen resolved into an aggregation of stars, it seemed to be like a luminous mass of vapour. At first it was surmised that it might be something of the nature of an atmosphere to the stars which it surrounded—or rather, that was one of the first reasonable suppositions, for all kinds of fanciful ideas were promulgated, such as it being an aperture in the heavens. This idea was speedily negatived, for it was remembered that something similar had been observed by Simon Marius, a German astronomer, and described by him in a work entitled "Mundus Jovialis," published in 1612. In the northern heavens, in the constellation *Andromeda*, can be seen with the naked eye a faintly marked spot of light. When Marius looked at this with his telescope he saw it was not a star, nor a group of stars, but a narrow elliptical spot of light, with apparently an area as large as that of the moon. It was not unlike a patch of grey mist, or, as Marius remarked, looked like a piece of transparent horn illuminated by a candle placed behind it. It could not be an atmosphere to a star, because there was no star near it, as in the case of the nebula seen by Huygens. An idea of the form of these nebulæ may be obtained from the figures, but it is impossible to reproduce their filmy, hazy appearance in a woodcut.

For a long time these nebulæ perplexed astronomers. A third was discovered, in 1665, by Abraham Ihle, in the constellation Sagittarius; a fourth was seen, in 1677, by Halley, in the southern constellation Centaurus. Kirch, in 1681, was the discoverer of a fifth. Hevelius saw another, and Halley subsequently discovered another, only much brighter than the last, and just visible to the naked eye. It is in the constellation Hercules, and has an irregular form, and an early drawing of it is shown in fig. 29. As telescopes were improved and rendered more powerful, some of these nebulæ, and in particular that in Hercules, were found to be clusters of very minute stars; and the opinion gradually gained weight that they might all be clusters of stars, only so very far off that they could not be seen separately, but appeared like a misty patch of light.

Nebulæ supposed to be star clusters.

Astronomers also discovered that some of the stars which seemed to the naked eye to be one star were really composed of two stars very close together. Thus Gassendi and Riccioli remarked that the star in the middle of the tail of the Great Bear was really composed of two stars, a bright one and a faint one. It was soon after discovered that the principal star in the constellation, Gemini, or α Geminorum, was composed of two equally bright stars placed very close to each other. The stars γ Virginis, γ Delphini, γ Arietis, β Cygni, also were seen to be composed of two stars close to each other; and Huygens discovered that the star θ Orionis was composed of three stars placed very close to one another in a kind of triangle. They did not regard this as anything very strange, for it seemed probable that it was a mere matter of chance that the two stars should be so close together. Thus with the naked eye there can be seen stars so close together as to seem almost to touch—as for instance the stars called ϵ Lyræ and α Capricorni.

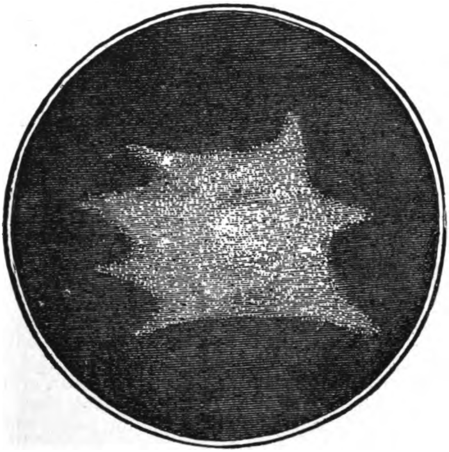


FIG. 29.—NEBULA IN HERCULES.

Astronomers had long been aware that occasionally new stars made their appearance in the heavens, and after shining brightly for a while gradually grew fainter and fainter until they disappeared altogether. Instances of such temporary stars were known long before the invention of the telescope. It was the appearance of a temporary star which led Hipparchus to form the first extant catalogue of stars. Temporary stars had also been seen in A.D. 390, 945, and 1264. A famous instance is that seen in 1572, when Tycho Brahé discovered a bright new star in the constellation Cassiopœia, when it was the brightest object of the kind in the heavens and visible in full daylight. It gradually grew fainter, and disappeared some time in 1574. In 1604 another temporary star was seen, this time in the constellation Serpentarius, springing into full brightness almost instantly, and surpassing any other star in the heavens. Like its predecessor, it gradually grew fainter, and disappeared early in 1606. Both these remarkable instances were before the discovery of the telescope, and no other case of the kind has occurred since, although minor instances have been seen. Thus Janssen in 1600 saw a bright new star in the constellation Cygnus; it gradually disappeared, but in 1657 this star reappeared and again faded out of sight. In 1670 Hevelius saw another temporary star in the same constellation. These instances, though probably of the same nature as the very brilliant new stars of 1572 and 1604, were of much less marked character.

Astronomers recognised before long some remarkable cases of change in the brightness of the stars. One of the strangest of these is the star o in the constellation Cetus. It was seen by Fabricius, in 1596, as a star of the 2nd magnitude, but soon disappearing, was considered by most astronomers a temporary star. Bayer saw it several years later, but did not identify it with the temporary star of Fabricius. In 1628 Phocylides, a Dutch astronomer, saw it gradually growing brighter, and was led to watch it with care. It became of the 2nd magnitude, and then growing fainter disappeared altogether. Later, however, he again saw it reappear, grow brighter, and disappear, and announced that it was a *variable star*. Bouillaud, a French astronomer, carefully watched it for years, and compared all the observations, and showed that it went through its variations in brightness in a period of nearly a year—being invisible for two or three months, visible only in a telescope for the same time, and for the remainder of the time visible as a faint star for four months and as a bright star for about half that time, shining like a star of the 2nd magnitude for over a fortnight.

One or two other stars were also found to be variable in brightness, but not to anything like the same degree as o Ceti; but to this day astronomers have been unable to discover any satisfactory explanation of the phenomenon. Many hypotheses have been advanced, but in no case with any real evidence in support of them. Certainly, when we consider that these variable stars are bodies of almost inconceivably enormous bulk, and that they lie remote from us at an inconceivably enormous distance, any increase or decrease in their brilliancy represents nature at work on a truly gigantic scale, which, if it raises in us feelings of the deepest wonder, must also excite the most lively curiosity.

By the middle of the century an important innovation had been introduced into stellar astronomy. It has been already mentioned that the earlier astronomers were accustomed to indicate one particular star by mentioning its place in the constellation—such as by saying it was on the tail of the Great Bear, the horn of Taurus, the heart of Leo, the right shoulder of Aquarius, etc., etc. Bayer, a German astronomer, published a celestial atlas in which the principal stars were designated by the Greek letters, α denoting the brightest star, β the second brightest, etc., etc. This was found to be a very considerable advantage, and rapidly came into general use, until by the end of the seventeenth century its use was nearly universal. It was only in England that the older method seemed to linger for some time longer. The letters of the Greek alphabet used by astronomers are as follows, the first being the capital and the other the small letter:—

Stars: their nomenclature.

Α α = Alpha
Β β = Beta
Γ γ = Gamma
Δ δ = Delta
Ε ϵ = Epsilon
Ζ ζ = Zeta
Η η = Eta
Θ θ = Theta
Ι ι = Iota
Κ κ = Kappa
Λ λ = Lambda
Μ μ = Mu

Ν ν = Nu
Ξ ξ = Xi
Ο ο = Omicron
Π π = Pi
Ρ ρ = Rho
Σ σ = Sigma
Τ τ = Tau
ϒ υ = Upsilon
Φ φ = Phi
Χ χ = Chi
Ψ ψ = Psi
Ω ω = Omega.

Bayer's notation is now in general use, and astronomers talk of α Orionis, β Cygni, γ Arietis, etc., meaning the star α in Orion, β in Cygnus, γ in Aries, etc.

CHAPTER V.

NEWTON'S CONTRIBUTIONS.

Explanation of the Motion of the Planets — Early Ideas — Newton's Early Labours—Apparent Discrepancy between Theory and Fact—Force necessary to retain a Planet in an Elliptical Orbit—Newton's Later Researches—Newton finds that Gravitation explains the Motion of the Moon—Newton's Theory of Universal Gravitation—Attraction of a Sphere—Does the Theory of Gravitation explain the Inequalities in the Motion of the Moon?—Newton finds it explains them—Halley induces Newton to publish his Discoveries—Newton's "Principia"—Newton's Discoveries generally accepted in England—Quarrels between Adherents of Newton and Leibnitz.

DURING the latter half of the seventeenth century many endeavours were made to account for the peculiarities of the motion of the planets by means of some physical cause. On the Continent the famous theory of ethereal vortices enunciated by Descartes held

Explanation of the motion of the planets.

Early ideas.

almost universal sway. In England and amongst some of the northern Continental astronomers an impression began to gain ground that the solar system was ruled by the force of gravity, gravity being the force by which bodies were attracted to the centre of the earth. It is commonly supposed that Sir Isaac Newton was the first to enunciate this view; but this is a mistake, for many of his contemporaries had earlier announced the same opinion. Huygens, in particular, had as early as 1671 established the principal laws which govern the motion of a body in a circular orbit, moving under a force like that of gravity tending to the centre of its orbit. Hooke, Roemer, Wren, and others had also discovered that if the planets moved in circles round the sun, it was possible to account for their motion by assuming them to be moving under the action of a force attracting them to the centre of the sun with an intensity varying inversely as the square of the distance.

Newton's early labours.

Apparent discrepancy between theory and fact.

Newton, in 1665, had already arrived at the same result, but his great genius led him to take a step further. If the planets moved round the sun through the action of gravity, then the moon must move round the earth through the action of gravity. Now, astronomers did not know the force of gravity of the sun, and considered themselves at liberty to assume it to be what they liked if it only fitted into their hypotheses; but they did know what was the force of gravity on the earth, and Newton saw it would be easy to find out if the moon did move in the way it ought to move if it were governed by the attraction of the earth. To do this it was necessary for him to know the diameter of the earth; and he took this to be 6,900 miles, which was the value he supposed to be true, and assumed that the distance of the moon from the earth was thirty times the diameter of the latter. Now, if the moon were really moved by the gravity of the earth, to find out the number of feet by which the force of gravity would move the moon in one second of time it was merely necessary to multiply the distance of the moon in feet by twice the square of the length of the circumference of a circle whose radius is unity divided by the number of seconds it took the moon to revolve round the earth. Performing the calculation, it appeared that the moon should move 0·00382 feet in a second, or this was the force of gravity at the distance of the moon. Now multiplying this by the square of the distance of the moon in radii of the earth, or $(60)^2$, it will give the attraction of gravity at the surface of the earth, because as the force of gravity varied inversely as the square of the distance, at the distance of the moon, or sixty times the radius of the earth, it would be diminished to $(\frac{1}{60})^2$ of its force at the surface of the earth. Now $0{\cdot}00382 \times (60)^2 = 13\frac{3}{4}$ feet, which is the distance at the surface of the earth that the force of gravity should make a body move in one second of time, if the moon were really moved by gravity. But Newton knew that the real distance was $16\frac{1}{10}$ feet; therefore, there was a considerable discrepancy, which Newton considered fatal to the theory. It seemed that it was not the gravity of the earth which made the moon revolve round the earth, and it was therefore most unlikely to be the force of gravity which made the planets move round the sun, for Newton saw that both effects must arise from the same cause.

In these researches on astronomy, Newton made use of his newly invented method of mathematical analyses, by him termed "the method of fluxions." He found it of the greatest assistance to him, and by its aid he was able to solve mathematical problems which could not have been successfully investigated by any other known method. The idea of an infinitesimal calculus was already known in a vague form to the mathematicians of the seventeenth century, and had enabled them to make some progress in the more recondite portions of mathematics, but Newton reduced this vague idea to a general method, based on exactly the same principles as the modern infinitesimal calculus. Appreciating the importance of his discovery, during the subsequent years Newton devoted his attention from time to time to strengthening his new system of analysis, though for years he refused to publish any account of his method. In fact, it was not until the early part of the following century that Newton published any detailed description of it, though its principles are pointed out in a note to his great work "The Principia."

Newton's success due to his improvement of the elder mathematics.

In 1673, Leibnitz, a famous German philosopher, learnt from Oldenburg, the secretary of the Royal Society of London, that Newton had invented a method for the quadrature of curves, or determining their areas. This led him to turn his attention to the more recondite branches of mathematics. Before long he invented a method of solving a class of problems depending on finding the maximum or minimum values of algebraical expression by means of an application of the principles of the infinitesimal calculus. This method he soon developed into the germ of the present differential and integral calculus; and in 1684 he published an account of his process. Its importance was at once appreciated by two great mathematicians, John and James Bernouilli, who, uniting with its inventor Leibnitz, rapidly developed this new method of analyses, and soon brought it to a state of considerable perfection. It rapidly spread over the Continent, where it was in general use some years before the publication of the first account of Newton's method of fluxions.

Leibnitz finds the differential calculus.

Both Hooke and Halley, not being aware of the fatal discrepancy between the force moving the moon and the gravity at the surface of the earth, energetically persevered in their labours to find out the physical cause of the motion of the planets. They soon saw that it was useless to continue to discuss cases of circular motion, for the planets did not move in circles, but in ellipses; and if the force which moved the planets was a force like the attraction of gravity, the planets must be attracted, not to the centre of the ellipse, but to a focus, for the sun was situated in the focus, not the centre, of the ellipse.

Suppose the planets were retained in their orbits by the attraction of the sun, what must be the law by which this force of attraction varied as the distance of the planet so that the planet might move in an ellipse around the sun placed in one of the foci? Halley endeavoured to solve this problem, but could not, for his mathematical knowledge was not sufficient. He applied therefore to Wren, who replied that he had tried to solve the problem but could not. He then applied to Hooke, who answered that it required the force to vary as the inverse square of the distance—that is to say, it was the same as in a circular orbit. Halley was delighted, and asked him to show his proof, but this Hooke resolutely refused to do, on the ground that he would wait until others trying had failed, and thus would value his discovery at its right estimation. In real truth, it would seem that Hooke had not obtained a strict proof, but established the proposition by general reasoning, regarding the ellipse as the case of a circle projected into an ellipse. This did not satisfy Halley, so he determined to apply to Newton, known to be the best English mathematician; and in August 1684 he proceeded to Cambridge.

Force necessary to retain a planet in an elliptical orbit.

In 1679 Newton had received a letter from Hooke in which it was stated that under certain conditions a body moving under the influence of a force varying as the inverse square of the distance would move in an ellipse. This attracted Newton's attention, who regarded it as an interesting mathematical problem, and set to work to determine the law by which the attraction must diminish with the distance to enable a body to move in an ellipse with the attracting body in one of the foci. By his splendid mathematical abilities he was able to establish by a rigid proof that it would be a force varying as the inverse square of the distance—that is to say, a force like gravity. In this, as in his subsequent researches, Newton was able to attack and solve problems by means of the infinitesimal calculus which it would have been impossible to solve by the earlier methods of mathematical investigation. Had it not been for his invention of the method of fluxions, a system of applying infinitesimal small quantities to the investigation of mathematical problems, it is probable that the law of gravitation might not have been established for many years.

Newton's later researches.

This result struck Newton as most remarkable, for it seemed to point strongly to gravitation as the ruling force of the solar system. But he remembered his earlier investigations which had shown him that the motion of the moon was inconsistent with this hypothesis. He determined, therefore, to re-examine his investigation. The theory was perfectly correct. His data, too, seemed right: the distance and period of the moon were certainly correct, so was the value of the force of gravity; then the value assumed for the diameter of the earth seemed right: but wait—had not Picard, the celebrated French astronomer, lately found a different value for the diameter of the earth? Newton remembered that Picard had. Further inquiry showed Newton that he was right, and that Picard, in 1679, by a careful measurement of the length of a terrestrial degree of latitude, had found nearly 4000 miles for the radius of the earth instead of 3450 miles, the value which had been employed by Newton. Astronomers regarded this new value as very much nearer the truth than the old, which had indeed been long suspected to be too small. Newton determined to recompute his result, using Picard's value of 8000 miles for the diameter of the earth. To his uncontrollable joy, the

Newton finds that gravitation explains motion of moon.

result came out 0·00448 feet for the deflection of the moon in one second of arc, which multiplied by $(60)^2$ became 16⅛ feet, and showed that the moon was retained moving in its orbit round the earth by the action of a force of attraction towards the centre of the earth, of a magnitude which would make a body of the terrestrial surface move 16⅛ feet in one second of time. As the force of gravity at the earth's surface would move a body of $16\frac{1}{10}$ feet in one second, it was evident that this force was identical with the force of gravity, or that the moon was kept in its orbit by the gravitation of the earth. Newton felt overjoyed at this result, and could scarcely control his feelings, for he fully recognised the grandeur of his discovery, and appreciated the enormous importance of the step he had made, in ascertaining the true cause governing the motion of the members of the solar system.

Newton's theory of universal gravitation.

The great genius of Newton enabled him to form a very true idea of the real nature of his discovery, and he saw that this force of gravity had nothing to do with any property attaching to the centre of the planets, but must be some inherent quality of the different particles which constituted the planets themselves. He recognised that it was unphilosophical to suppose that the particles of the earth should attract the moon, and the particles of the sun attract the planets, without supposing that those of the earth were attracted by those of the moon and those of the sun attracted by those of the planets. Otherwise, why should the earth attract the moon and not the sun? He therefore at once arrived at the famous law of universal gravitation, the law that *every particle of matter in the universe attracts every other particle, with a force varying inversely as the square of the distance between them, and directly as the mass of the attracting particle.*

Newton felt that this was only a theory—the true theory as we know now, but at that time merely a theory, which might or might not be true. He felt that something more was required to prove its correctness. He therefore devoted his time to seeing whether it would not explain other features of the solar system beyond merely accounting for the moon and planets moving in ellipses round their primaries placed in one of the foci of the ellipse, and showing that the moon moved in an orbit under the influence of a force exactly equal to that of terrestrial gravitation.

Attraction of a sphere.

From the symmetrical way in which the particles are arranged in a sphere, Newton saw that the attraction of one spherical body on another would be exactly the same as if the entire force of attraction were placed at the centre of the sphere. He found no difficulty in giving a mathematical proof of this, and thus accounted for the fact that the attraction of the sun and planets seemed as if it resided in their centres. He next showed that the motions of the satellites of Saturn and Jupiter were in accord with the theory of gravitation.

Newton then took a crucial test of his theory—the inequalities in the motion of the moon. We have already seen that the planets move round the sun in fixed ellipses, and are not disturbed by any irregularities in their motion. But we have also seen that the moon, though moving round the earth in an ellipse, does so in an ellipse which is always slowly changing its position, and that the moon does not move uniformly in this ellipse, but is liable to several inequalities in its motion. Now, it was evident to Newton that if the theory of universal gravitation were correct it must be capable of accounting for these peculiarities in the motion of the moon. He determined to ascertain if it did. Had the earth and moon been by themselves, Newton knew that gravity could not account for these inequalities; he saw that their source must be looked for in the attraction of some other body. His attention was immediately directed to the sun—by far the largest body in the solar system, and therefore the most likely to exercise the most powerful attraction. It was evident that from the attraction of the sun on the moon, this body could not move round the earth in the same manner as it would were it not for this attraction, for otherwise we should have a variable force always acting and yet never producing any effect. Newton was led, therefore, to carefully calculate, by means of his own splendid mathematical processes, the exact effect of the attraction of the sun on the moon in its motion around the earth. To his great satisfaction, he found it account for every one; the theory of gravity showing that the moon should move in the irregular way it did move, and giving the same value for the inequalities that they were known to have. He felt he had now demonstrated the truth of the law of gravitation, and he was content.

Does the theory of gravitation explain the inequalities in the motion of the moon?

Newton finds it explains them.

When Halley reached Cambridge, in August 1684, he propounded his problem to Newton. To his great delight he learnt that Newton had not only completely solved his problem, but had gone much further, and in a series of a dozen propositions had given a rigid proof of the principal laws governing the motion of bodies under the action of a force like gravity. These demonstrations were transmitted to Halley after his return to London, and communicated by him to the Royal Society of London. Halley paid another visit to Newton, and learnt of the further investigations of the philosopher—namely, those on the motion of the moon—and at the earnest solicitation of Halley, Newton promised to send an account of his researches to the Royal Society. In April 1686 Newton redeemed his promise by sending the first part of his great work, entitled *Philosophiæ Naturalis Principia Mathematica*, and commonly termed *The Principia*. Later on he sent to Halley the remaining portion, and in 1687 the whole was printed and published at the sole expense of Halley.

Halley induces Newton to publish his discoveries.

It does not come within our scope to give an account of the numerous grand discoveries and elegant investigations contained in the *Principia*, the most important scientific work that had ever been published. We must be content with briefly mentioning that it showed how the problems of mechanics, such as the motions of different bodies, could be reduced to problems of pure mathematics, and in this manner solved the principal problems of the mechanism of the heavens. It showed the principal known phenomena of astronomy were to be fully explained on the theory of gravitation. Besides accounting for the motion of the moon and planets, it explained how gravitation accounted for the phenomena of the tides, for the motion of the polar axis of the earth, and for the motion of comets. It showed how the figure of the earth must be a sphere slightly flattened at the poles, or be, as it is called, an oblate spheroid; and it showed how the force of gravity would vary at different places on the earth; and in an investigation of the properties of the pendulum, explained why Richer had found a pendulum beating seconds in Paris lost time when it was carried to the equator.

Newton's "Principia."

This grand work of Newton attracted the immediate attention of the scientific world. In England it made immense progress, and was generally accepted as true by all the principal men of science. The rising mathematicians of the day at once accepted and expounded its teachings, and as the older professors were replaced it was at once introduced into the Universities. The Scottish Universities took it up first, at the instance of the eminent mathematicians David and James Gregory. Keil introduced it at Oxford, and afterwards Clarke and Whiston at Cambridge.

Newton's discoveries generally accepted in England.

On the Continent it was received with caution, the older astronomers and mathematicians regarding it with doubt; some, in fact, like Cassini, Huygens, and Maraldi, rejecting it. Leibnitz, the Bernouillis, and other mathematicians regarded it with some hostility and jealousy, but this might have been removed by further examination. Some years went by, when a slight event settled the question. A French mathematician remarked that Leibnitz' method of infinitesimal calculus was the first account published, giving him the right of priority. Later, De Duillier, another mathematician, retorted that the testimony of his friends showed that Newton was the first inventor of this method, and that Leibnitz might have really taken his ideas from Newton, as Newton had sent him some information on the subject in 1676. This was a spark which gave rise to a tremendous explosion. Leibnitz denied the charge. Newton's friends, Keil, Cotes, Pemberton, Taylor, reiterated it, and brought down on them the Bernouillis and the adherents of Leibnitz. The quarrel waxed strong and vigorous, charges met charges, strife engendered strife, until bitter hostility divided the English from the Continental mathematicians, and prejudice reigned triumphant over all. On the one hand, the English mathematicians despised and condemned everything advocated by the Continental mathematicians, and absolutely refused to take heed of or make any use of the great developments they were effecting in the infinitesimal calculus. They confined themselves to praising and dwelling on the achievements of Newton, doing little to advance the method of fluxions or to extend still more the discoveries he had made. On the other hand, the Continental astronomers refused to have anything to do with either Newton or his disciples, and aware of the superior condition of the differential and integral calculus of Leibnitz, looked with scorn on the less perfectly developed method of fluxions. They thus rejected almost

Newton's "Principia" rejected on the Continent.

Quarrels between adherents of Newton and Leibnitz.

unexamined the grand discovery of Newton, and prejudiced left the *Principia* almost unread. Only when time had removed the adherents on each side did this bitter but needless quarrel fall to the ground. But it left its mark deeply scored. Though on the Continent the truth slowly made its power felt, and the new generation of mathematicians took up Newton's work and by series after series of brilliant discoveries carried it to a pinnacle of glory which had never been dreamt of by its author, yet in England mathematical astronomy slept for a century, and when the English mathematicians awoke they found themselves a century behind their Continental rivals.

CHAPTER VI.

FOUNDATION OF SYSTEMATIC OBSERVATION.

Discovery of the Velocity of Light—Apparent Insufficiency of Römer's Theory—Discovery of Aberration—Discovery of Nutation—Steady Progress in Astronomy— Greenwich Observatory— Paris Observatory — Controversy about the Figure of the Earth—Halley's Comet—Expedition to watch the Transit of Venus—Solar Parallax—New Methods of determining the Solar Parallax—Lunar Parallax.

WE have now to notice some important discoveries that were made, and which had the greatest influence on the accuracy of astronomical observation.

Whilst the Danish astronomer Olaus Römer was staying in Paris to assist Picard, he obtained a number of observations of the eclipses of Jupiter's satellites, but particularly of the first satellite. With the view, probably, of obtaining data to correct the tables of the satellites, he proceeded to reduce these observations to their proper form. He found that the eclipses of the satellites seemed to be retarded as the earth moved farther away from the planet. Thus, when the earth was at *a* in fig. 30 the satellite seemed to be eclipsed 7½ minutes earlier than when the earth was at either *b* or *c*. Pondering over the cause of this, it struck him that a perfectly analogous effect would be produced were light to take any appreciable time to pass from the satellite to the earth. Because, if this were so, we should not see the satellite disappear at the moment it was lost in the shadow of the planet, for the light waves which left the planet the instant before it was eclipsed in the shadow would not reach the observer for some time afterwards, and the satellite would not seem to vanish until these last waves of light had reached the observer, and would appear therefore as much later as the time which it took for them to travel the distance between the satellite and the earth. Now, as the earth when at *b* or *c* is farther away from the planet than when at *a*, the light would take a longer time to reach the earth, and the satellites would remain a longer time visible than when the earth was at *a*. Römer concluded, therefore, that light took seven minutes to travel the distance of the earth from the sun, and that this accounted for the observed retardation in the times of the eclipses.

Discovery of the velocity of light.

Römer announced his discovery in a communication to the Paris Academy of Sciences in the year 1675. It excited much attention, and at first met with general approbation, but slowly lost ground when it came to be further investigated. Cassini had held the same view even prior to Römer; but he had found it to be inconsistent with some of his observations, so he felt obliged to reject it. He now re-examined the subject, but with the same result. He pointed out that though it accounted well for the phenomena presented by the I. satellite, it was inconsistent with the observations of the other satellites. Accordingly, in his new tables of Jupiter's satellites, published in 1693, he rejected Römer's theory, and introduced instead some arbitrary corrections. The English Astronomer Royal, Flamstead, was also adverse to the theory of Römer, but it found a warm advocate in the illustrious Halley. Later, in 1707, Maraldi, the nephew of Cassini, and an energetic observer of the satellites of Jupiter, advanced some powerful arguments against the validity of the theory of Römer, founded on some phenomena which ought to be observed were it true, but which he showed had not been observed. Gradually astronomers were swayed over to the opinion that Römer's theory was unsound, and that the phenomena of the eclipses of Jupiter's satellites did not indicate the existence of an "equation of light," as it was called, or a correction depending on the velocity of light. It seemed almost certain that the retardation detected by Römer arose in some different manner.

Apparent insufficency of Römer's theory.

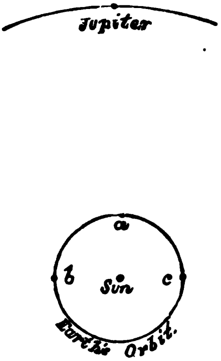


FIG. 30.

At this period Molyneux, an English statesman, and an amateur astronomer, erected an instrument called a zenith sector, and consisting of a small arc of a circle of large diameter, firmly fixed perpendicularly in the meridian, in a manner which allowed of very accurate measurement being made of the distance of stars from the zenith. Molyneux, with a young friend Bradley, observed the zenith distance of the star γ Draconis, with the view of detecting any annual parallax which the star might exhibit. In the middle of December 1725, Bradley carefully watched the passage of the star across the meridian, and marked on the zenith sector its distance from the zenith. If the star had any annual parallax, it would slowly move towards the north, but they knew that it would be some time before any motion would be observable. On the 17th December Bradley resolved to adjust more accurately the mark indicating the zenith distance of the star, so he carefully watched the passage of the star across the meridian. He noticed that the star was really a little more south than he had placed it on his former observation, and he wondered how he came to make such an error. He mentioned it to Molyneux, and they agreed to very carefully observe the star, so as to make sure that there was

Discovery of aberration.

no error. The next fine day was the 20th, and Molyneux and Bradley sallied out together to observe the passage of γ Draconis. To their astonishment the star was found to be still to the south. They therefore determined the place of the star with extreme accuracy, and waited for the next fine night. Again they observed its passage across the instrument, and again they found it farther south. There could be no doubt: the star was certainly moving south. This entirely perplexed them: it was certainly not due to any parallax in the star, for it was moving in the wrong direction. They resolved, therefore, to carefully watch it from day to day. They found the star steadily advance towards the south until March, when it was more than 20″ to the south of its place in December, and after remaining almost stationary it then slowly moved back towards the north, and in June was back at its old distance from the zenith. But it did not stop, but moved on towards the north, until in September it was more than 20″ to the north of its old place; then after again remaining nearly stationary it returned towards the south, until by December 1726 it was back in the same place that it occupied in the preceding December.

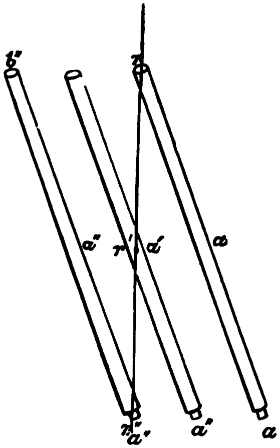


FIG. 31.

This mysterious motion sorely puzzled Molyneux and Bradley, and the latter determined to have erected a zenith sector of his own. In August 1727 the instrument was finished, and Bradley commenced his observations, not confining himself to γ Draconis, but choosing eleven other stars to observe as well. Molyneux died while the observations were in progress, but Bradley, continuing the work by himself, found that they all exhibited a similar periodical change, but at different times of the year and in different manners, and in a way which was inconsistent with any hypothesis which he could imagine.

At last the idea struck him that he might try if the velocity of light could have anything to do with the phenomenon; for he had tried everything else, and he was an advocate of Römer's hypothesis, having already introduced it into his tables of Jupiter's satellites. He readily found that the motion of the earth in its orbit would slightly alter the apparent places of the stars unless the rays of light move enormously quicker than the earth. This is easily understood by the figure (31). Suppose that rr'' is a pencil of light coming from the zenith, and that the earth was stationary, then the telescope a of our zenith sector must also be directed towards the zenith. But if the earth is moving, our telescope must be directed towards the side to which it is moving. Thus, when the pencil of light is at r, the telescope will be at a; but by the time the pencil has reached r', the telescope has moved to *a′*: so unless the telescope was directed on one side, as shown, the pencil of light would no longer be on the middle of the telescope, but would have touched one of the sides. Finally, when the pencil reaches the observer at *r″* the telescope and observer would have moved to the position *a″*. From the motion of the earth, therefore, a pencil of light which really came from the zenith would seem to come in the direction *b″a″*, and the star which sent the light would seem to be in the direction *b″a″*. It can be shown that if the pencil of light move 10,000 times quicker than the earth, or the distance *a a″* be $\frac{1}{10000}$ of the distance *r r″*, the angle *r a a″* will be 21″, or a star like γ Draconis will seem to be altered by 21″ on either side of its mean place.

This *aberration* of light, as Bradley termed it, completely accounted for the motion of the stars which he had observed, and he triumphantly communicated an account of his discovery to the Royal Society in 1729. Its importance was at once recognized, and it was at once seen to completely confirm Römer's discovery of the velocity of light. For whilst Bradley's observation indicated 8 m. 12 s. for the time which light would take to cross the radius of the earth's orbit, Römer had found rather more than 7 m.—no important difference considering the imperfect state of the tables of Jupiter's satellites. Thus at a time when Römer's discovery seemed altogether discredited, it was completely verified in a manner of which its author could not have even dreamt.

Discovery of nutation.

Bradley had noticed during his observations some peculiar differences between the theoretical places of the stars and the observed places. He could not account for these, and determined to continue his observations, to see what law, if any, was followed by these discrepancies. Years went by, but still he was unable to assign any cause to these variations. By 1736 he had arrived at the opinion that it might be due to a slight motion of the axis of the earth, and it seemed to have a similar period to the revolution of the nodes of the orbit of the moon. By 1745 he found that these variations had gone through a complete periodical change in eighteen years, which was the time required by the nodes of the orbit of the moon to perform one revolution. He was able to announce that the polar axis of the earth moved once in eighteen years in a small circle 18″ in diameter around its mean place, and he called this phenomenon the *nutation*. Subsequent observation has completely confirmed this discovery, and it has been shown to arise from the attraction of the moon on the equatorial regions of the earth.

Steady progress in astronomy.

Practical astronomy had now settled down into quieter times, and for years no great discovery was made with the telescope. At the different observatories which had been founded in different states, regular observations were made of the principal heavenly bodies. Foremost stands the long series of invaluable observations made at Greenwich, which under the able superintendence of the different Astronomers Royal supplied the principal mass of exact observations for perfecting our knowledge of the motion of the moon and planets and the position of the principal stars. Flamstead, the first Astronomer Royal, was succeeded in 1720

Greenwich Observatory.

Paris Observatory.

by Edmund Halley, who in turn was succeeded in 1742 by James Bradley, the discoverer of aberration and nutation. The observations of Bradley were made with a transit instrument and two mural quadrants, and are the only observations of this period which are comparable in accuracy with those of modern days. He was succeeded in 1762 by Maskelyne, who continued assiduously to obtain observations of the moon. planets, and principal stars, until his death in 1818. The Royal Observatory at Paris was founded on a different system, there being no real head, but a number of observers who devoted themselves to such investigations as they thought proper. Cassini was succeeded by his son Cassini II. and Maraldi; but the principal observations during the period 1686—1730 were made by La Hire, Cassini II., and Maraldi the elder; and from 1730 to 1760 by the younger Maraldi and Lemonnier, and subsequently by Lemonnier, Lacaille, and Cassini III. The observations consist principally of eclipses, occultations of stars, and the phenomena of Jupiter's satellites, and the determination of the places of the stars. The observatory at Rome was principally devoted to cursory observation of the planets, and its best observations were made by Bianchini and Boscovitch. At St. Petersburg the observatory was first under the direction of Delisle (1725-48)—some of whose observations have proved of great value—and then under that of Heinsius. During this period the most celebrated German astronomer was Tobias Mayer, who was head of the observatory of Gottingen between 1750 and 1760.

Although these observations have been of the greatest service to astronomy, enabling astronomers to improve the tables of the planets and their satellites, to catalogue the stars, and to more accurately determine the value of the procession of the equinoxes, the velocity of light, and the value of aberration, etc., they do not demand any detailed account. The method by which they were made has been already described; and though slight improvements were introduced, no material alterations were effected.

Controversy about figure of the earth.

During the middle of the eighteenth century much attention was devoted by French astronomers to determining the real diameter and figure of the earth. Newton, by the theory of gravitation, had shown that the earth was a very slightly flattened sphere, with a polar diameter about $\frac{1}{230}$ part shorter than the equatorial diameter, or, as it is termed, an oblate spheroid with an ellipticity of $\frac{1}{230}$. In the early part of the eighteenth century, Cassini and La Hire measured arcs of the meridian, and obtained results which seemed to indicate that the polar axis was longer than the equatorial. This gave rise to a bitter controversy about the true figure of the earth, which lasted for many years; the observations made in Europe seeming to favour the result obtained by Cassini. At last, in 1735, the Paris Academy sent out two expeditions, one to measure an arc in Peru, near the equator, and the other to measure an arc in Lapland. These expeditions were conclusive in favour of the Newtonian theory; and in 1740 a remeasurement of Cassini's arc of the meridian showed the existence of some small errors which, when rectified, led to the same result.

Subsequently other arcs of the meridian were measured, and it was rendered certain that the earth was in figure an oblate spheroid, of ellipticity about $\frac{1}{300}$, with a polar axis of about 7899, and an equatorial diameter of 7,925, miles.

In 1704 Halley was led to calculate the observed path of a number of comets which had been seen, and he was surprised to find that the path of the comet of 1682 was nearly identical with that seen in 1607, seventy-five years earlier, and observed by Kepler. Proceeding with his work, he was amazed to find that the comet of 1531, which had been observed by Appian, seemed to move likewise in the same path. This looked very much as if they were three apparitions of one comet, which took about 75½ years to return; for it was very improbable that three distinct comets should move in paths so close to each other. He determined to examine if there was any comet seen in 1456, or 75 years before the comet seen by Appian. He was delighted to find that there was, and that this comet moved in a similar path to the other three. Continuing his investigation, he found records of a comet in 1380, or 76 years earlier, and in 1305, or 75 years still earlier. He felt convinced that all these observations were apparitions of the same comet, which revolved round the sun once in 75½ years. He predicted, therefore, that this comet, now called Halley's comet, would return and pass its perihelion, or nearest distance to the sun, in the end of 1758, and should therefore be visible some time in the summer or autumn of that year. This prediction caused much interest, and when 1758 came all astronomers were anxiously on the look-out for the expected comet. August 1758 came and went, but no comet; September and October came and went, but still no comet. Things were becoming serious, and it began to look as if Halley's prediction was visionary. November dawned, but still no comet, and many astronomers openly expressed their views that Halley's theory of a periodical comet was quite erroneous. On the 14th November, a young but even then celebrated mathematician, named Clairaut, announced that he had mathematically investigated the theory of the comet, and had found that the attraction of the planets Jupiter and Saturn would delay the return of the comet by nearly a year, and that it would not return to its perihelion until April 1759. This news was satisfactory, for if it were true it showed that the comet might yet be seen. Astronomers redoubled their search, but November went and December came, and still no comet. Christmas time arrived, but not the comet.

Halley's comet.

On Christmas Day, a Saxon amateur astronomer, named George Palitsch, discovered a nebulous spot in the heavens, which had moved appreciably by the next day. It was the long-expected comet come back at last, as Halley had predicted. It was observed with great care, and found to pass its perihelion in March 1759, exactly one month earlier than the date fixed by Clairaut. In 1835 Halley's comet once more returned, but theoretical astronomy was now in a far more perfect condition, and its return was predicted to within a day of the real time.

In 1761, and again in 1769, numerous expeditions were organised to watch the transit of Venus across the sun, with the view of determining the solar parallax and thus ascertaining the distance of the

Expedition to watch transit of Venus.

sun. Gregory was the first to point out the advantages of the transits of Venus for this purpose, and Halley had energetically advocated the method. It is easy to understand how the distance of the sun was to be ascertained, by noticing how the planet's path across the sun seemed to be displaced when it was viewed from different parts of the earth. Thus, if in fig. 32 *s* be the place of Venus from a spot *e* on the earth, as seen from the spot *e′* it will appear to be at *s′*, and from the spot *e″* appear to be at *s″*. Now, the distance of Venus from the sun is known by astronomy to be $\frac{8}{11}$ of the distance of the sun from the earth, so that if *v s* = $\frac{8}{11}$, then *v e* will be $\frac{3}{11}$, and therefore the distance *s′ s″* will be $\frac{8}{11} + \frac{3}{11}$, or $\frac{8}{3}$ of the distance *e′ e″*; so that if *e′ e″* be 6,000 miles, then *s′ s″* will be 16,000 miles. Now, viewed from the earth, the planet Venus will seem to cross the sun along the path *s s*, *s′ s′*, *s″ s″*, fig. 33, according as it is seen from the points *e*, *e′*, *e*,″ and the distance between *s′ s′* and *s″ s″* can easily be found when we know how much longer *s″ s″* is than *s′ s′*, and this will be equal to the difference in time it will take Venus to move over *s′ s′* and *s″ s′*.

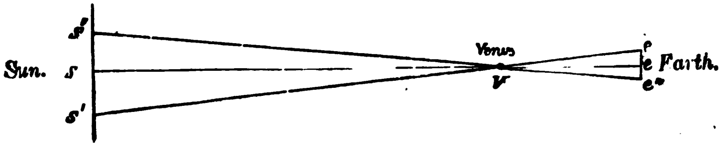


FIG. 32.

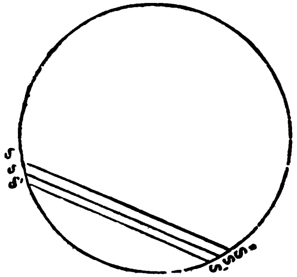


FIG 33.

Now, the observers of the transits, when these results came to be properly compared, found that the distance between *s′s′* and *s″s″* was 35·0″. Therefore we arrive at the result that 16,000 miles at the distance of the sun occupied 35″·0, and by geometry we know that 16.000 miles, to appear only 35″, must be removed to a distance of 94,290,000 miles, which must therefore be the distance of the sun.

Then, taking the radius of the earth as 3,962 miles, by dividing 35″ by $\frac{3962}{10000}$ we find that the parallax of the sun is 8·67″. This was the value deduced by Laplace from the transits of Venus of 1761 and 1769.

Solar parallax.

Lacaille, a French astronomer, had at an earlier period, from a comparison of the difference in the position of the planet Mars, as seen from the Cape of Good Hope and the observatories of Greenwich and Paris, during the autumn of 1751, found that at the Cape of Good Hope, Mars seemed systematically 40″ north of the place it seemed to occupy in Europe. As the distance of the planet from the earth was only one-third of the distance of the sun, and as the distance between the Cape of Good Hope and the European observatories was $\frac{13}{10}$ times the earth's radius, the solar parallax must be equal to $40'' \times \frac{1}{3} \times \frac{10}{13} = 10{\cdot}24''$. This value was thought to be too great.

New methods of determining solar parallax.

Subsequently Tobias Mayer of Gottingen, a famous German astronomer, endeavoured to determine the distance of the sun by an entirely new principle. When the moon is between its first quarter and its last quarter, it is in the portion of its orbit which is beyond the path of the earth, and so farther from the sun than when it is in the other half of its orbit, and in consequence it moves slower during the latter half than it does it during the former half. The amount by which it moves slower or quicker is in direct proportion to the ratio of the distances of the sun and moon from the earth. Consequently, at the time of first quarter, when the moon has been moving with diminished speed for half its revolution, it is behind its place by nearly a fifteenth part of its diameter; and at the time of third quarter, when the moon is moving correspondingly faster for a similar period, it is nearly a fifteenth of its diameter ahead of what would otherwise be its place. The maximum amount of this variation is equal to 14½ times the solar parallax. According to Tobias Mayer, the exact amount of this variation was 123·5″, and he named it the *parallactic inequality*, as its value depended on the value of the solar parallax. Dividing this by 14½, it gives 8·7″ for the solar parallax. Subsequently Laplace in the same manner found 8·6″.

Lunar parallax.

Lalande employed Lacaille's observations of the moon made at the Cape of Good Hope in 1751, to determine a new value of the lunar parallax, by comparing them with corresponding observations made by himself at Berlin, and found that the parallax of the moon was equal to 57′ 3·7″. Subsequently, towards the end of the century, Burg, an astronomer of Vienna, compared Lacaille's observations with those made by Bradley at Greenwich, and deduced the value of 57′ 1·8″ for the lunar parallax. There no longer remained any uncertainty as to this.

CHAPTER VII.

Modern Mathematical Astronomy.

Establishment of the Theory of Gravitation—Euler, Clairaut, D'Alembert—Further Discoveries through the Mathematical Investigation of the Theory of Gravitation—Lagrange and Laplace—Difference in their Powers—Discovery of the Stability of the Solar System—Other Brilliant Discoveries.

In course of time there sunk into oblivion the bitter controversy that had been waged between the schools of Leibnitz and Newton, and the rising generation of Continental mathematicians were able to take an unprejudiced view of the state of science. Already in 1722 Maupertius, a French mathematician, had entered upon a strong defence of the theory of gravitation, and in 1738 the celebrated Voltaire wrote a brief but powerful exposition of the numerous discoveries and theories of Newton. Mairan, Louville, and others had also directed attention to the beauties of the theory of gravitation.

Establishment of theory of gravitation.

At that time there was a trio of able young rising mathematicians living in France. Euler, the eldest, though but thirty-three, had already rendered his name distinguished through his discoveries in the pure mathematics, by which he showed himself to be a most skilful and powerful analyst. Clairaut and D'Alembert were seven or eight years younger, but had both signalised themselves by their mathematical achievements. In 1740 D'Alembert showed how to reduce problems of dynamics to questions of equilibrium, and thus at one step removed the difficulties in forming the analytical base on which to investigate problems dealing with the motions of bodies or systems of bodies. Clairaut, directing his attention to Newton's theory of gravitation, applied the powers of the infinitesimal calculus to the investigation of the figure of the earth, and mathematically established some beautiful theorems with regard to the figure and attractions of the earth. These were published in 1743, and were the firstfruits of the application of Leibnitz' calculus of differentials to the theory of gravitation. In the same year he turned his attention to the theory of the moon. Both Euler and D'Alembert were also working on the same problem, the famous problem of three bodies,—Given a body moving under the influence of gravitation in an ellipse round a second body and disturbed in its motion by the attraction of a third body, find the law of its motion.

Euler, Clairaut, D'Alembert.

All three arrived at successful results, and deduced in an unexceptionable manner the theoretical values of the principal inequalities in the motion of the moon. In one respect, however, they all three failed to make theory agree with observation; for like Newton they found theoretically that the lunar perigee should move only half as fast as it really did. For some time this inexplicable discrepancy threw grave doubts on the correctness, or rather on the sufficiency, of the theory of gravity. Some philosophers urged that the theory should be modified so as to reconcile it with observation. In 1749 Clairaut successfully overcame this difficulty, and showed that it arose from his colleagues and himself having omitted to take into account the inequalities of the motion of the moon when considering the action of the sun upon it, but had considered it as moving in a regular ellipse. On rectifying this emission he showed that the theoretical value agreed perfectly with that which had been observed. This was a great triumph for the theory of gravitation, and firmly established its truth in the eyes of astronomers.

Determined to gather fresh laurels on this magnificent field, these three mathematicians turned their attention to other of the grand problems of astronomy, and between 1745 and 1765 made important discoveries concerning the motion of the planets. They were soon joined in their investigations by Lalande, Mayer, and Bailly, and the theory of the planets and their satellites on the theory of gravitation were placed on a satisfactory footing. It is impossible to give any idea of the numerous brilliant discoveries which were made known in the course of these investigations into the theory of astronomy. By their ingenuity these celebrated mathematicians triumphed over difficulty after difficulty, and showed how Newton's theory of gravitation accounted for the most recondite phenomena of the heavens.

Further discoveries through the mathematical investigation of the theory of gravitation.

At this period there arose a new worker in these fields of research, the illustrious Lagrange, destined to achieve still more brilliant discoveries and to enrol his name as the greatest master of mathematical analysis. When only in his twenty-seventh year, in a masterly paper published in 1763, Lagrange showed how to effect some important improvements in the theoretical investigations of his predecessors. Shortly afterwards his younger but equally illustrious rival Laplace, when scarcely past his majority, made himself known by skilfully carrying his investigations to a more complete extent than either Euler or Lagrange, and in this manner rectifying some imperfect results at which they had arrived by having omitted some important considerations.

Lagrange and Laplace.

From this period until the end of the century, Lagrange and Laplace rivalled each other in an equal race for pre-eminence, and brilliant discovery after discovery rewarded their investigations. Lagrange, gifted with a complete mastery over mathematical analysis, boldly attacked problem after problem in the infinitesimal calculus, and triumphing over difficulty after difficulty, successfully developed it in all directions, and showed how to investigate question after question which had previously been held to be beyond its powers. Laplace, a most able mathematician, though not possessing Lagrange's unrivalled mastery over mathematical analysis, yet possessed a sagacity of mind which seemed to enable him to penetrate almost intuitively into the secrets of nature and to reap discovery after discovery where others would see little to discover. Nay, in more than one case he achieved a victory over problems which had fairly baffled his rival Lagrange, who did not always realise the real import of his discoveries.

Difference in their powers.

They investigated the theory of the different planets, and determined the values of the different perturbations or inequalities in their motions due to their mutual attraction. The secular inequalities or slow variation in the orbits of the planets were next examined, and

Discover the stability of the solar system.

Other brilliant discoveries.

in a series of brilliant investigations it was shown that the orbits of the planets would always retain the same mean distance from the sun and revolve around that luminary in the same mean period. Thus, though the eccentricity and inclination of the orbits, and the positions of their perihelia and nodes would slowly vary, the orbits of the planets would always retain their present character. They showed that the planets could neither fall into the sun, nor come into collision with each other. Astronomers had made known by observation the existence of a peculiar inequality in the motion of Jupiter and Saturn, by which these planets were periodically retarded and accelerated in their motions in their orbits. Laplace showed that this arose from their mutual attraction, and depended on the fact that Jupiter revolved five times in its orbit in the same period that Saturn revolved twice, and that from this cause their mutual attraction produced inequalities which went on accumulating for many years. Observation had also made known the fact that the moon was moving quicker in its orbit than it used to, and this quickening, while very small (amounting to only 10″ in a century), was called its secular acceleration. After having baffled mathematicians for thirty years, it was found by Laplace to arise from a slow decrease in the eccentricity of the elliptical orbit of the earth, which enabled the attraction of the earth to make the moon move quicker round it. Turning his attention to the motion of the moon, Laplace next showed that the ellipticity or difference in the length of the equatorial and polar diameter of the earth would introduce small inequalities into the motion of the moon, and showed that one of these had been discovered by Mayer, who was ignorant of its origin. From the observed value of these inequalities, he was able to show that the polar axis of the earth must be $\frac{1}{300}$ part shorter than the equatorial axis. From another inequality in the motion of the moon—that already referred to as the parallactic inequality—he was able to show that the distance of the sun from the earth must be about 94½ millions of miles.

The theory of the tides, the phenomena of refraction, the figure of the earth and moon, the precession of the equinoxes, the nutation of the axis of the earth, the obliquity of the ecliptic, the motion of the satellites of Jupiter, and the ring of Saturn,—all these engaged the attention of Laplace and Lagrange, and all were placed on a very much more perfect footing. Theoretical astronomy was indeed placed on the firm foundation which it now occupies, and later investigations have possessed the character of mere extensions and perfections of the results which were embodied in the researches of Lagrange and Laplace.

CHAPTER VIII.

New Telescopes and Discoveries.

Imperfections of the Old Telescope—Discovery of the Achromatic Telescope—Invention of Reflecting Telescopes—Herschel—Discovers a New Body—The Planet Uranus—Discovery of two Satellites to Uranus—Schröter—New Satellites to Saturn—New Double Stars discovered—Discovery of Binary Stars—Colours of Stars—Catalogues of Nebulæ—Some Nebulæ Clusters of Stars.

By the middle of the eighteenth century great improvements had been introduced into the construction of telescopes. The earlier astronomical telescopes had object-glasses consisting of single lenses, and when these object-glasses had a short focal length, the different rays of light did not meet in a point, which is necessary to enable them to give a sharp distinct image, but the rays were spread confusedly over a small area, so that when any object was looked at it appeared indistinct and surrounded by a broad fringe of coloured light. To get rid of these imperfections it was necessary to make the focal length of these telescopes at least one hundred times the diameter of the object-glass. Now, astronomers wanted to employ magnifying powers of 122 to 150 in their observations, and would have liked to have used powers of 200. But to use these powers they had to employ telescopes with object-glasses of 3 to 5 inches in diameter, or they found that the objects were too faint and indistinct to be properly seen. They had therefore to make their telescopes at least 300 to 500 inches in length, or 25 to 50 feet long, and found that they were still better if twice this length.

Imperfections of the old telescope.

Newton had thought it possible that by making the object-glass of two or more lenses the rays might be brought to a point in a short focal length, but after experimenting declared it to be impossible. At last, in 1755, Dollond, a London optician, succeeded in constructing an object-glass of two lenses which did bring the rays of light to almost a point, and got rid to a very great extent of the injurious fringe of coloured light. These object-glasses were called *achromatic* object-glasses, and by using them it was found possible to construct telescopes of 3 to 4 inches aperture and only 6 to 7 feet in length, which should magnify 150 to 200 times and yet give still more distinct views than the best of the earlier telescopes of twenty times their length. The only difficulty in constructing them was to get large enough pieces of the peculiar glass that they were made of.

Discovery of the achromatic telescope.

In the preceding century, Gregory, a Scotch mathematician, had suggested a new method of constructing telescopes, which was to bring the rays of light to a focus by reflection from a curved mirror. These telescopes were therefore called *reflecting* telescopes. Newton showed that it was possible to make telescopes of this kind by constructing a very small one which he presented to the Royal Society. During the seventeenth century, however, no progress was made in construct-

Invention of reflecting telescopes.

ing these telescopes. In 1722, however, Halley constructed a large reflecting telescope with a reflector, or speculum as it was called, of six inches in diameter and rather over four feet in focus. In 1723 this telescope was presented to the Royal Society, and on being tested it was found to be as powerful as a telescope of 123 feet in length presented to the Society by Huygens. Others now began to construct reflecting telescopes, because owing to their short focus they were much more easy to manage than the very long refracting telescopes commonly used. Their great drawback was that they were very difficult to construct. In 1732 an Edinburgh optician named Short made some very successful reflecting telescopes, and soon acquired a great celebrity, and from 1740 to 1760 a great number of these reflecting telescopes were made. They commonly possessed specula of three to seven inches aperture, and a focal length of only three to eight feet, and magnified from 120 to 250 times. They were found a great improvement over the common telescope, and nearly equal to the achromatics, but could be made more powerful than these latter.

Herschel.

In 1774, William Herschel, an amateur astronomer of Bath, succeeded, after many trials, in constructing with his own hands a five-inch reflector, and with this he commenced surveying the heavens. Feeling desirous of obtaining a still more powerful instrument, he recommenced his labours and constructed several seven-inch reflectors, one of which was of very good quality. Later he succeeded in turning out a nine-inch reflector of ten feet focus, of quality very superior to the ordinary reflectors.

Discovers a new body.

On the night of March 13th, 1781, he was engaged in examining some stars in the constellation Gemini, with his seven-inch reflector and a magnifying power of 227. He came across a star which looked very much larger than the others. In his telescope the stars usually appeared about 1″ to 2″ in diameter, but this one seemed more than twice that size. He thought it very remarkable, and scrutinised it closely, when it seemed to him to be unlike a star in appearance. He therefore applied a higher power to his telescope, and the result confirmed his suspicion: it certainly did not look like a star. He began to suspect that it might be a comet. Surely no star could look like that? He determined to watch it attentively, for if it were a comet then it must be slowly moving. He noticed that it was near a faint star, and he carefully estimated its position with regard to this star, so that when he looked at it on the next evening if it was moving he would at once detect it, as it would then be in a different position with regard to this star. He resumed his observations of the other stars, but could not resist looking from time to time at his suspected comet. But no, he was not deceived—it did look bigger than the other stars: and stay, surely it had moved a little! He waited a little longer, and felt sure it was moving. Yes, unquestionably it had moved, for its distance from the faint star had certainly altered. It must be a comet.

Supposed to be a comet.

He immediately wrote to Maskelyne, the Astronomer Royal, and announced that he had discovered a comet, whereupon the news was at once transmitted to the principal astronomers in Europe. Messier, Lalande, Lemonnier, and many other astronomers, at once turned their attention to the new comet, and by observations determined its place and motion. The comet moved very slowly, almost parallel to the ecliptic, but the astronomers knew that as it approached the sun it would soon move much faster. A month went by, but the comet still moved as slowly as ever, and astronomers began to be surprised; it ought to be moving faster and faster, but it didn't. It was a most annoying comet. Laplace, Mechain, etc., attempted to calculate the orbit of this new comet; but it was a most perverse body—they could not make its motion fit into a cometary orbit. It would not begin to move faster, as a comet ought to do, but steadily went on at its old rate of motion.

Differs from other comets.

At last De Saron began to suspect that this comet was a very different kind of body to the other comets, and did not come close to the sun as they were known to; and in May he announced that, by supposing the comet to always remain farther away from the sun than Saturn, he could make an orbit which would fit better into the path of the comet than any which had yet been tried. Astronomers soon found that this was correct; but then, what a remarkable comet it must be!—no comet had ever been known to have such an extraordinary orbit. It was a unique comet.

Towards the end of the month of May, Lexell, a celebrated astronomer famous for his cometary discoveries, began some new researches on this comet which had baffled all anticipation and which seemed to have such an extraordinary character. He thought to himself that it was strange that a comet should exist so utterly unlike its colleagues. Its slow and uniform motion seemed very peculiar and suggestive. Every path which had been suggested had failed, because it made the comet begin to move faster, whereas it still kept its rate of motion unchanged. He thought he would see how a perfectly uniform rate of motion would account for the motion of the comet. He soon found that by assuming the comet to move in a circle round the sun, at about twice the distance of Saturn, its motion could be perfectly represented. But then such a body would not be a comet—it must be a planet.

Is it a planet?

This announcement roused the attention of all astronomers. A new planet!—a most important discovery; and redoubled attention was paid to the new body. Several months went by, and no doubt remained: it was a planet, and our family of planets had received a new acquisition. In January 1783, Laplace showed that the new planet moved in a slightly elliptical orbit, at a distance from the sun of nineteen times the mean distance of the earth. Three names were suggested for the new planet. Herschel proposed the name of *Georgium Sidus*, after his royal patron George III. Astronomers, however, would not listen to this. Lalande proposed *Herschel*, and for some time this name was in use; but it gradually gave way in favour of the name *Uranus*, proposed by Bode, and this is now universally employed.

Is the planet Uranus.

By repeated measurement the diameter of the new planet was found to be a little over 4″, and its real diameter to be 35,000 miles. It was therefore 4½ times larger than the earth, approaching in size the giant planets Jupiter and Saturn. It was easily calculated that it would take eighty-four years to move round the sun.

Discovery of two satellites to Uranus.

Herschel had, after great labour, succeeded in constructing a very large reflector, having an aperture of eighteen inches and a focus of twenty feet, it being by far the largest and most powerful telescope then in existence.* In January 1787 he determined to search with this instrument for any satellites which Uranus might possess. After several nights' careful watching he was successful, and detected two satellites, both extremely faint bodies, one moving round the planet in 8¾ days and the other in 13½ days. These satellites, unlike any others, move in orbits nearly perpendicular to the orbit of the planet. From their extreme minuteness no other observer was able to see them for a period of forty years; in fact, there did not exist another telescope powerful enough to show them. Later Herschel suspected that four other satellites might exist, but in this he seems to have been mistaken.

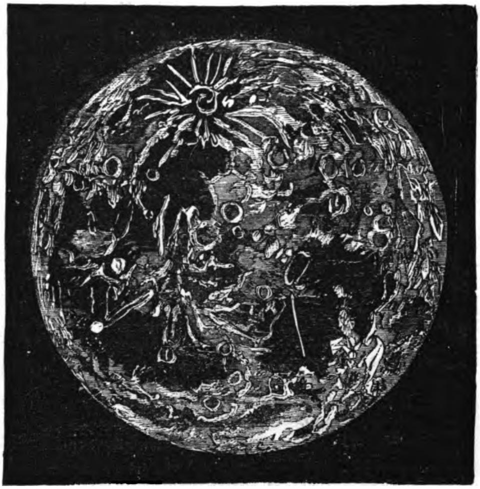


FIG. 34.—EARLY DRAWING OF MOON.

Schroter.

Between the years 1780 and 1800, Schröter, of Lilienthal, in Hanover, obtained some fine reflecting telescopes—one being of 7 inches aperture, another of 9½ inches aperture and 13 feet length, and finally one of 26 feet in length and 19 inches in aperture. With these instruments he made many observations of the details visible on the planets. He recognized traces of the existence of dense atmospheres to Mercury and Venus. He drew with care many portions of the lunar surface, and believed he had found indications of the existence of volcanoes. And in this he was confirmed by the opinion of Sir W. Herschel. Schröter also measured the height of many mountains in the moon, and showed that they were loftier than the terrestrial mountains. He also detected grey spots on Venus and Mercury, and determined their period of rotation.

---

* Subsequently he succeeded in making a telescope of still larger size, having an aperture of four feet and a focal length of forty feet. This enormous telescope, though defining moderately well, was found of more use for very faint objects than for studying the appearance of the planets.

On the 28th of August, 1789, Sir William Herschel directed his largest telescope to the planet Saturn, which was then in a position so that its belt appeared like a narrow line. He saw no less than six stars in a straight line in the plane of the ring. He at once suspected that they might all be satellites. He watched them attentively, and soon saw that they were all moving with the planet; so that his surmise was correct and they were all satellites. Now, as Saturn was only known to have five satellites, one of these must be new. Further observations proved that the smallest and innermost satellite, or the one nearest the planet, was new. It is now called Enceladus, and revolves round the planet in 33 hours. Continuing his observations of this new satellite, on the 17th of September his attention was directed to another still smaller than Enceladus, and still closer to the planet. It is now named Mimas, and revolves round the planet in $22\frac{2}{3}$ hours. Enceladus was seen by several of his contemporaries; but Mimas was so close to the planet, and so faint, that many years elapsed before another telescope was constructed that would show it.

New satellites to Saturn.

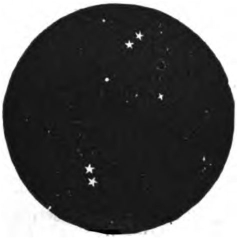


FIG. 35.—ε LYRÆ.

By means of his powerful telescopes Sir William Herschel was enabled to make many important contributions to astronomy. Up to 1780 only two score or so double stars were known; but in 1782 Herschel communicated a paper to the Royal Society containing a list of 269 double stars, nearly all of which had been discovered by himself. In 1785 he communicated another list containing observations of 400 or 500 more.

New double stars discovered.

Astronomers fix the positions of double stars by measuring what are called their distance and position angle. These will be understood from the figure (fig. 36), where there is shown the principal star, A, with three smaller stars, *a*, *b*, *c*, around it. It is what is called a double star, though, as we see, really a quadruple star; but every star which has one or more companions is said to be a double star.

The distance in seconds of arc between the stars A and *a* is said to be the distance of the star; and the direction of the star *a* from A is said to be its *position angle.* These position angles are shown on the outer ring, and we see that *a* has a *position angle* of 225°. In the same manner *b* is said to have a position angle of 80 , and *c* one of 320°. The arrow marks the apparent path of the stars from E. to W., and N. E. S. W. show the position of these parts of the heavens, the star being supposed to be seen in an astronomical telescope, which makes everything look upside-down, so that the N. is at the bottom and the S. at the top. Now, Herschel determined the places of all his double stars, fixing their distances and position angles.

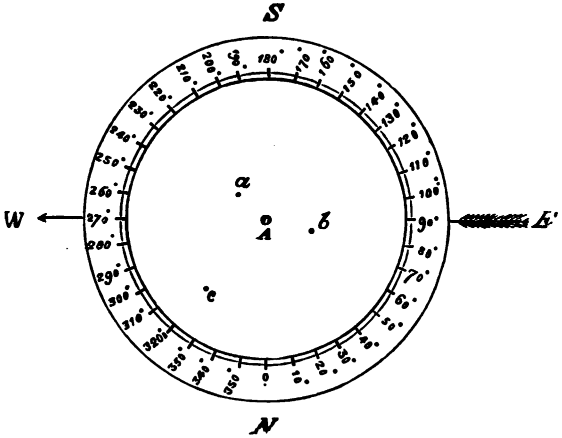


FIG. 36.

In 1767, Mitchel, an enthusiastic amateur astronomer, advanced the view that some of these double stars were really systems of stars, like our sun and planets, and not, as had been commonly supposed, merely two stars which accidentally appeared close to each other. In 1784 he strongly urged this point, and suggested that if his view were correct, some of these double stars would be seen to be moving round each other. Most astronomers thought that this view was fanciful, and little attention was paid to it. In 1803, however,

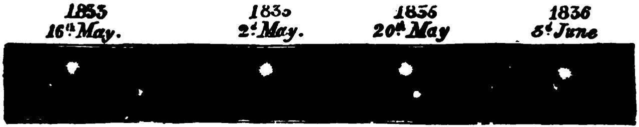


FIG. 37.—POSITION OF THE TWO STARS OF γ VIRGINIS.*

---

* Not inverted, in these figures, as in a telescope.

Herschel, in a communication to the Royal Society, pointed out that his observations entirely confirmed this theory; and by comparing his observation made in 1782-4 with those made subsequently, he showed that some of the smaller stars were actually moving round the larger. From his observations he found that the smaller star in γ Leonis would revolve round the larger in 1,200 years, and in δ Serpentis the period of revolution was 375 years.

Discovery of Binary stars.

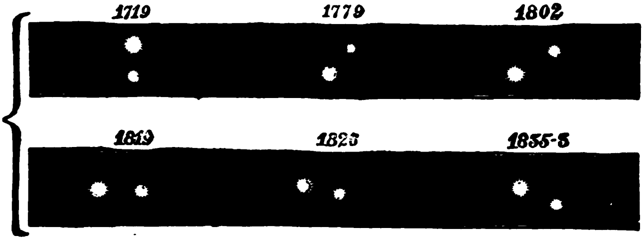


FIG. 38.—POSITION OF THE TWO STARS OF CASTOR.

This was a remarkable discovery, and showed astronomers that there existed other systems of bodies in close connection beside the solar system. It seemed, however, certain that these double stars were not suns and planets, but systems with double, triple, and quadruple suns.

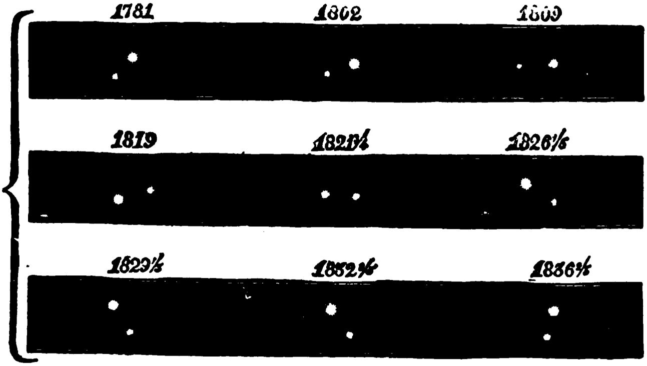


FIG. 39 —POSITION OF THE STARS OF ζ URSÆ MAJORIS.

Herschel also pointed out that the stars showed many variations in colour; most of them were white, some were yellow, and others were reddish. These variations had long been known; but Herschel showed that there were red stars, blue stars, green stars, and purple stars. In fact, one double star dis-

Colours of stars.

covered by him had one star blue and the other green, another pair were blue and orange, etc., etc.

We have already mentioned that astronomers in the seventeenth century had detected some variable stars in the heavens. During the latter part of the eighteenth century Goodricke, Herschel, and others detected a considerable number more. Thus β Persei was found to vary in brightness in a very short time from the 2nd to the 4th magnitude. According to Goodricke it appeared a star of the 2nd magnitude for 2 days 13 hours, then in 3½ hours fell in brightness to the 4th magnitude, and then slowly rose again to the 2nd magnitude; the entire change occupying only 2 days 21 hours. Again, the star β Lyræ was found to vary between the 3rd and 5th magnitude in about 6½ days. The origin of these variations still remains unknown.

Catalogues of nebulæ.

In 1755 Lacaille communicated to the Paris Academy of Science a catalogue of forty-four nebulæ he had observed when at the Cape of Good Hope. Some of these appeared like nebulæ only when they were seen in small telescopes and with a low power, but when more powerful optical means were employed they were seen to be clusters of very small stars. Others always appeared like nebulous patches of light, even in the most powerful telescopes that he had with him. Later, in 1771, and again in 1784, Messier, a French astronomer, published a catalogue of nebulæ observed by him. The complete list consisted of 103 nebulæ, most of which were new. To this day many of the principal nebulæ are designated by the number in this catalogue; thus the great nebula in Andromeda, discovered by Marius, is known as 31 Messier or 31 M. Andromeda, and another equally celebrated nebula in Lyræ, known as the ring or annular nebula, because it resembles a nebulous ring, is called 57 M. Lyræ. All these nebulæ were easily visible in small telescopes of four or five inches aperture.

Some nebulæ clusters of stars.

In 1784-6 Sir William Herschel turned his powerful instrument on the heavens, and began to search for new nebulæ. He met with great success, for many nebulæ too faint to be seen with less powerful telescopes were very conspicuous in his magnificent instruments. In 1786 he sent the Royal Society a first list of a thousand new nebulæ and clusters resembling nebulæ when seen with smaller instruments. In 1789 this was followed by a second list of a similar number; and in 1802 he forwarded a third list of five hundred more. Many of the nebulæ which Halley, Messier, and others had been unable to see otherwise than as faint patches of nebulous light, were resolved by his powerful instrument into gorgeous clusters of thousands of faint stars. In fact, it gradually became the opinion of astronomers that all nebulæ were merely clusters of stars, so enormously far off that the separate stars could not be seen, so that they appeared like faint spots of light.

CHAPTER IX.

The Minor Planets.

Bode's Law—Looking for a New Planet—Piazzi discovers a New Star—Renewed Search for Suspected New Planet—Discovery of Ceres—Olbers discovers a New Star—The Planet Pallas—The New Planets Fragments of a Large One—The Discovery of Juno—The Discovery of Vesta.

From a very early period it had been noticed that in their distance from the sun the planets followed a very regular order. Suppose the mean distance of the earth from the sun to be taken as 10, then the distance of the different members of the solar system will be given by the first column of figures of the following table:—

Actual distances.		Calculated distances.	Difference.
Mercury	3·9	$4 = 4$	— 0·1
Venus	7·2	$7 = 4 + 3 \times 2.$	+ 0·2
Earth	10·0	$10 = 4 + 3 \times 2^1$	+ 0·0
Mars	15·2	$16 = 4 + 3 \times 2^2$	— 0·8
——		$28 = 4 + 3 \times 2^3$	
Jupiter	52·0	$52 = 4 + 3 \times 2^4$	+ 0·0
Saturn	95·4	$100 = 4 + 3 \times 2^5$	— 4·6
Uranus	191·8	$196 = 4 + 3 \times 2^6$	— 4·2

In the year 1772 a German astronomer, Bode, drew attention to a very curious law, which seemed to connect together the distances of the planets of the solar system. This law is shown in the second column of figures in the preceding table, and it will be seen it closely agrees with the real distances of all the planets which were then known except Saturn, for Uranus had not been discovered at this period. Even in the case of Saturn it only differed by less than one-twentieth part. This law is commonly known as Bode's law, and is a very curious arithmetical coincidence. It will be noticed that one of the terms in this law, the term between Mars and Jupiter, is not represented by any planet in the solar system; and to render the coincidence complete, it would be necessary to suppose that here was the place of a missing planet.

Bode's law.

This curious law of Bode's, and the remarkable gap in the system of planets which it seemed to indicate, made a considerable impression on German astronomers, and led to a good deal of speculation. Was it, or was it not, probable that there was really a gap in the system of planets of the solar system between Mars and Jupiter? Was there really a planet missing? While many of the older astronomers were incredulous, many of the younger astronomers were deeply impressed with the view that there really ought to be another member of the solar system between Mars and Jupiter. In 1781 the discovery of Uranus gave an opportunity of further testing this law of Bode's; and in 1783 it was found by Laplace that the mean distance of Uranus agreed closely with the law of Bode, thus materially strengthening in an unexpected manner this curious law. The younger and more enthusiastic astronomers were now convinced that a new planet probably existed in the gap between Mars and Jupiter, where the place of a planet was indicated by Bode's remarkable law. Later on, when many of them were in a position to initiate series of observations for themselves, De Zach, one of their number, succeeded in establishing an association of twenty-four astronomers, who undertook to search the heavens for this supposed missing member of the solar system. For this purpose the zodiac was divided into twenty-four narrow belts or zones, and each astronomer undertook the examination of one of these zones with the view of detecting this missing planet.

Probable nature of new planet.

If there really were a missing planet, what must be its probable nature? It could not be large, or it would shine so brightly that it would have been long discovered. Thus, supposing the planet to be in the place indicated by Bode's law, it would approach the earth within one hundred and sixty million miles, whilst Mars came within a third of this distance. It would seem to move in the heavens at the rate of about a quarter of a degree per day, and revolve round the sun once in about five years. If, then, the planet were as large as Mars—that is, about 4000 miles in diameter—it would under favourable conditions shine like a third magnitude star, or be nearly half as bright as Saturn. But astronomers knew that a planet as bright as even a fifth magnitude star, moving as quickly as this, could not have escaped being detected long before then, so that the missing planet could not shine much brighter than a sixth magnitude star. The missing planet could not therefore be more than a fourth of the diameter of Mars. A planet of this size would have a real diameter of 1000 miles, or only one-eighth of the real size of the moon, and appear under the most favourable condition as a round disc about 2″ of arc in diameter. With the telescopes in the possession of nearly all astronomers, a planet of this size could not in appearance be distinguished from a star, except by its daily motion of, on an average, nearly a quarter of a degree. To detect, then, this missing planet, if it really existed, it would be necessary to examine and determine the place of every star of less than the fifth magnitude on separate days, and see if any of them had moved. Now, there are several thousand stars between the fifth and seventh magnitudes which would have to be examined, so that the work undertaken by the society of twenty-four astronomers, organized by De Zach, was one of some length. Towards the very end of the last century the society commenced their observations; each member undertaking to thoroughly examine some particular portion of the zodiac.

For some time no result was to be expected, as it would be necessary for each observer to become thoroughly familiar with the region assigned to him. It was not, therefore, likely that any discovery would be made for at least a year.

At this time, Piazzi, a celebrated Italian astronomer, was engaged in observing the heavens with the view of forming a great catalogue of stars—a purpose which he successfully carried out. On comparing his observations of the stars in the constellation of Taurus with those of an earlier observer Piazzi found that he had not seen a star which was contained in the catalogue of the earlier observer. Surprised at this omission, he carefully looked in this part of the heavens for this star. He could not find it. Piazzi looked on the next night, and the next again, but still without success; which is not remarkable, for it is now known that this star did not really exist, but was inserted in the earlier catalogue by mistake. On the first night of the present century, January 1st, 1801, Piazzi looked for the fourth time, and still failed to see the missing star, but he saw a small star which he did not remember having noticed. On the next night, to his surprise, the star seemed to have moved a little, so he carefully determined its place. On the next night, January 3rd, 1801, he again carefully determined the place of the star, and found that it had moved nearly 5½′. There could be no doubt that the new star was slowly moving. In appearance this new star could not be distinguished from an ordinary star of between the seventh and eighth magnitude, and it had no trace of the disc of a planet. Piazzi continued to watch the motion of this moving star, and found that it moved more slowly every day until about January 10th, when it was stationary in its motion in longitude. On January 13th it commenced again to move, but in the opposite direction, and continued to move at a gradually increasing rate until February 11th, 1801. A serious illness here put a stop to Piazzi's observations. From his observations Piazzi was convinced that this moving star was really a new planet, and from its rate of motion evidently a planet situated between Mars and Jupiter.

Piazzi discovers a new star.

On January 27th, 1801, Piazzi wrote to the Italian astronomer Oriani, and the German astronomer Bode, and gave an account of his discovery; but by the time that his letters reached their destination, and had been made known by their recipients to other astronomers, the sun had approached so closely to the position of the new planet that it could not be observed. The news of the discovery at once aroused the attention of astronomers, being a striking confirmation of the view held by so many German astronomers that Bode's law was not a mere accidental coincidence. Preparations were at once made to observe this new planet during the following autumn, when it would be again visible. Gauss, and other eminent masters of the mathematical branches of astronomy, endeavoured to deduce the elements of the orbit of the new body from the observations forwarded by Piazzi, and in this manner ascertain whereabouts the planet would be when it was again visible. In this, however, they were baffled: the observations sent by Piazzi were too few and too close together for this purpose. This was a serious difficulty, for unless astronomers knew where to look for this new planet, its re-discovery would be very difficult, and might occupy years. From this difficulty they were partially relieved by receiving further information from Piazzi, who now transmitted to them his additional observations, made between January 26th and February 11th. From these observations Gauss was enabled to approximately determine the elements of the orbit of the new body, and thus to publish an ephemeris showing the probable place of the planet in the heavens.

Renewed search for suspected new planet.

Autumn came round, and astronomers anxiously examined the heavens to re-discover this new body. Where the new planet ought to be according to the ephemeris, no such body could be seen; nor could it be seen or discovered anywhere near this place. Night after night went by without the planet having been re-discovered, so that astronomers must have become anxious.

The ephemeris calculated by Gauss was founded on such imperfect data, that it could only be regarded as indicating the probable place near which the planet would be found. Harding, De Zach, and Olbers were particularly persevering in their search, sweeping night after night the portion of the heavens in which the new planet was probably moving, and carefully studying all the small stars, to see if they could detect one which was moving. Still no trace of the missing planet could be found. But this labour, apparently so fruitless, was to bear unexpected fruit. At last, on the very last night of the year, De Zach detected a star of about the seventh magnitude which seemed to him to have moved during the interval between his observations. He looked more closely, and carefully watched the star. It was moving. The next evening left no doubt: he had re-discovered the missing planet, and he at once announced his success. He had, however, been but just in time, for Olbers had independently re-discovered the planet on the very next evening. The new body was now carefully observed, and thus material was obtained for the accurate determination of its orbit.

Discovery of Ceres.

This new member of the solar system was named *Ceres* by its discoverer Piazzi, and it was found to move in an orbit whose mean distance was 2·77, whilst the place assigned to it by Bode's law was 2·80. When it came to be examined with the telescope so as to determine its size, it was found that even with the most powerful telescopes it could not be distinguished in appearance from a star. There it was, a little round disc, less than a second of arc in diameter, and perfectly undistinguishable from a star of the 7½ magnitude. It could not therefore possibly be more than five hundred miles in diameter, and judging from its brightness, was probably only two hundred miles in diameter. It was therefore a miniature planet, very unlike any other member of the planetary system.

Three months after the re-discovery of Ceres, Olbers was examining a portion of the constellation Virgo, near where he had seen Ceres. In this region, which he had carefully studied, Olbers had noticed, when searching for the new planet, two 7½ magnitude stars, forming a pretty though distant pair in a region where there are not many stars of this brightness. But when he turned his telescope on this pair, to his surprise he found that there were no longer two stars, but three stars, forming an equilateral triangle. This seemed remarkable, for he could not imagine how he could have overlooked the third star. Overlooked it?—it was impossible. It must be a variable star which he had discovered—that is to say, a star which, though usually very faint, yet at times became much brighter—and a number of such stars were known. He left the telescope and referred to some star catalogues, and found that, whilst they recorded the place of the two stars he had originally seen, they made no mention of the third star, which, if it were a variable star, must then have been faint, and so passed by un-

Olbers discovers a new star.

noticed. He returned, therefore, to determine the exact place of this new variable star. He then noticed that the triangle of stars no longer seemed an equilateral triangle, but the variable seemed appreciably nearer one star than another. Yet he distinctly recollected that it seemed to be an equilateral triangle when he first looked. Looking at it again, it seemed to be still more unlike an equilateral triangle, nor did it seem to have quite the same place amongst the still smaller stars. It really seemed to have moved. Half an hour later there could no longer be any doubt; it must be moving. Olbers continued to watch it, and in two hours found that it had moved over sixty seconds of arc. Surely it could not be *another planet!* The next night he returned to this region, and found that the strange star had moved right away from the known pair, and was now nearly half a degree from its old place. It must be a new planet. It was a new planet.

The planet Pallas.

This second new planet was named *Pallas* by its discoverer, and was found to be a companion to Ceres discovered by Piazzi. Its mean distance was ascertained to be 2·67, and its orbit was remarkable not only for its eccentricity, which was greater than that of Mercury, and nearly three times as great as even that of Mars, but for its great inclination to the ecliptic, which, being 34° 39′, is very much greater than that of any other planet. In size it resembled Ceres, as in even the most powerful telescope it could not be distinguished in appearance from an ordinary 7½ magnitude star. Its diameter therefore probably could not exceed 200 miles.

The new planets fragments of a large one.

Astronomers were now slightly perplexed. They had expected one planet, but had found two, and two such small planets. Bode's law would satisfactorily account for one planet, but what of the other? And then, as just stated, they were so very small—so small that a thousand would not make a planet as large even as Mars. They were, in fact, merely little bits of planets, or, as they were called, *asteroids* or *planetoids*. Little bits of planets?—Why not fragments of one large planet which had been destroyed at some early epoch? This idea struck Olbers as a very possible one. It would account for everything: for their small size, similarity in distance from the sun, and variation in eccentricity and inclination. Olbers therefore made known this hypothesis, that Ceres and Pallas were possibly the fragments of a large planet which had been destroyed by some gigantic internal convulsion at some long-past epoch. Moreover, as he pointed out, if this hypothesis were true, there must be other, even if smaller, fragments in existence, and, if searched for, it ought to be possible to discover them. This fascinating hypothesis of Olbers' at once attracted the attention of astronomers, and led many to undertake a search for further fragments of this hypothetical exploded planet.

With the view of facilitating the search for these further fragments, Harding, a Hanoverian astronomer, undertook the construction of a map of all the principal small stars near the intersection of the paths of the two minor planets Ceres and Pallas. By comparing this chart with the heavens it would be possible to recognise at once any new minor planet which had moved into this region, for it would be absent from the map, and be obviously new. On September 2nd, 1804, whilst engaged on this work, he noticed a star which he had not previously seen, and was led to suspect that it might be a new planet. September 3rd was cloudy, and he could not observe; but on September 4th he again turned his telescope on this region. The star was gone: it had moved a considerable distance. Subsequent observation showed that it was a third minor planet, and a companion to Ceres and Pallas, so that its discovery tended to materially strengthen the hypothesis of Olbers. This new planet was named *Juno*, and, like the others, was so small that it could not be distinguished from an ordinary star. It appears when in opposition like an eighth magnitude star, so that its real diameter cannot much exceed 150 miles, and is probably not more than 100 miles. Its mean distance is 2·67, or almost the same as that of Pallas, whilst the eccentricity of its orbit is even greater than that of Pallas. The inclination of its orbit, though greater than that of Ceres, is less than one-half of that of Pallas.

Discovers Juno.

Encouraged by the discovery of Juno, which so strongly confirmed his views, Olbers perseveringly continued his search for yet other fragments of his hypothetical planet. But the year went by without any success rewarding his exertions. The year 1805 came and went, and still no result accrued. This was not promising; it looked as if all the larger fragments had been discovered, and that he must look amongst the ninth magnitude stars for an additional planet. Nevertheless Olbers persevered with his search during the whole of the next year; but 1806 went by, like 1805, without his being successful. Sanguine of the truth of his hypothesis, Olbers determined to devote yet another year to the work, which was much facilitated by the knowledge of the configuration of the heavens he had obtained by his labours since 1801. On March 28th, 1807, whilst examining the eighth magnitude stars in Virgo, he suddenly came across a bright sixth magnitude star where he had never noticed anything of the kind. He felt pretty certain that there had been no such star here before. It must be yet another planet. But its brilliancy was against this; it was surely too bright. If there really existed a planet of this brightness, he or others would have discovered its motion long ago. It could be seen with the naked eye even. Olbers carefully determined its place, and then waited. It certainly seemed to be in motion. He again determined its place. There was a sensible difference. It was in motion; it was a planet.

Searches for other fragments.

Discovers Vesta.

The new planet was named *Vesta*, and it was found by Gauss to be another companion to Ceres and Pallas. Its mean distance was 2·30, and the eccentricity of its orbit about as great as that of Mars. Its inclination was not excessive. Like the other members of the group, it is too small to be distinguishable in appearance from a star, and its real diameter probably does not exceed 400 miles.

Olbers rested content with the discovery of Vesta, and his hypothesis was generally favourably regarded as accounting for the origin of the minor planets in a probable manner. Other astronomers were deterred from carrying out the search by its obvious arduous nature, as shown by the three years' labour that it had taken Olbers to discover Vesta, although his previous experience had so well qualified him for the work. Astronomers in general were content. The opening years of the nineteenth century had added four new planets to the solar system, even though these planets were small. In the meantime the investigation of the theory of the motion and perturbation of these new members of the solar system was found to furnish ample matter to tax the ingenuity of the workers in the field of mathematical astronomy, owing to the difficulties presented by their great eccentricities and inclinations.

CHAPTER X.

MODERN DISCOVERIES.

New Tables of the Planets constructed—Discordance between Observed and Tabulated Places of Uranus—Star Catalogues—Increased Accuracy of Observation—New Standard Catalogues—Survey of the Heavens—Star Maps—Changes suspected in the Moon—New Lunar Maps—Real Nature of the Lunar Surface—Moon supposed to be a Desert—No apparent Lunar Changes—Views held by Selenographers—Improvements on the Lunar Theory—The Sun—Observations of Total Solar Eclipses—Mercury—Atmosphere of Venus—Mars—Spots on Jupiter—Saturn's Rings—Discovery of a New Ring—Discovery of a New Satellite—The Satellites of Uranus—Neptune—New Minor Planets—Comets of Short Period—Stellar Discoveries.

New tables of the planets constructed.

ASTRONOMY now entered on a new phase; the era of remarkable discoveries had closed, and the energies of astronomers were now mainly devoted to applying the numerous brilliant discoveries which had been made to the improvement of the practice of astronomy. Thus, founding their calculations on the theory as developed by Laplace in his great work the *Mécanique Celeste*, Burg in 1806, Burckhardt in 1812, and Damoiseau in 1828, published tables of the motion of the moon. The tables of Burckhardt were founded partly on the reduction of a great number of observations, and sufficed to indicate the time of the moon's transit across the meridian to within a couple of seconds of time; whilst those of Damoiseau, which were founded entirely on the theory, were so accurate that the error seldom exceeded one second of time. In 1804 De Zach published tables of the sun, but these were quickly superseded by those constructed by Carlini, an Italian astronomer, which were published in 1810, and for nearly half a century were in general use, giving the place of the sun with small errors rarely amounting to more than a fraction of a second of time. In 1810 Von Lindenau published tables of the motion of the planet Venus, in the succeeding year tables of Mars, and in 1813 tables of Mercury, all founded on the theory of the planets as developed by Laplace in the "Mécanique Celeste." In 1821 Bouvard published tables of the greater planets, Jupiter, Saturn, and Uranus, founded on the same theory. All these tables represented the motion of the planets with considerable accuracy, and far beyond anything which could have been hoped for in the preceding century, thus forcibly illustrating the enormous advances in astronomy which had resulted from the grand theoretical investigations of the great mathematicians

Laplace and Lagrange. In general it may be stated that the theory of the motion of the planets was now so well known, that errors greater than a second in the predicted time of the planet's transit were of rare occurrence. In fact, astronomers had now to concern themselves with errors of a tenth or so of a second of time. The only exception to this accord between theory and observation was in the case of the lately discovered planet Uranus. Bouvard found himself quite unable to reconcile the modern and older observations of this planet; so, thinking the older ones were in error, he founded his tables on the more modern observations. As years went by, however, it was soon discovered that these tables of Bouvard's failed to properly represent the motion of the planet, and soon a considerable discordance arose between the tabular and observed place of the planet—a discordance which gave rise to much speculation amongst astronomers as to its probable source. In 1817 Delambre published new tables of Jupiter's satellites, tables which were much more accurate than any which had preceded them; but these were in turn superseded in 1836 by Damoiseau's tables, which continue in use up to the present time.

Discordance between observed and tabular places of Uranus.

During this period much attention was given to determining the places of the stars. This work was divided into two divisions: firstly, the determination of the exact places of a small number of the brighter stars, which were to be used to determine the errors in the clocks, and were therefore termed *clock stars* or *standard stars*; and secondly, the determination of the approximate place of the remainder of the stars which were visible in ordinary telescopes.

Star catalogues.

We have already described the method employed by astronomers to determine the places of the stars—namely, by observing the time of their passage across the meridian, by observing their transit across the wires of a transit instrument, and by noting their altitude as they pass the meridian. During the early part of the present century great improvements were introduced into the construction of these instruments, so that astronomers were now able to observe the transit of a star and its apparent altitude with such accuracy that the errors were usually only a small fraction of a second of time, and a second or so of arc. By making, therefore, half a dozen observations of a star, they were able to determine its place to within a tenth of a second of time in its right ascension, and a fraction of a second of arc in its declination. To enable this to be done, however, it was essential that the errors of the astronomical clocks should be exactly known; and this could only be done by comparing the true time of the passage of certain of the brighter stars with the observed time as shown by the clock, when the difference would be the error of the clock. It was necessary, therefore, to determine the places of these clock or standard stars with great precision by repeatedly observing them, so that in the mean of the multitude of observations all the accidental errors might be destroyed. Maskelyne was one of the first to publish a really accurate catalogue of clock stars, thirty-six in number; and for long it served as the foundation of all other observations, by

Increased accuracy of observation.

being used to determine the errors of the astronomical clocks. In 1807 Piazzi published a new catalogue of some hundred and twenty clock stars. Until 1833 these were the only accurate clock-star catalogues in existence. Since then a considerable number of accurate star catalogues have been published. To render sufficiently accurate the places of stars to be used as clock stars, it is deemed necessary that they should be founded on at least a hundred observations.

New standard catalogues.

But it was quite unnecessary for ordinary purposes to observe each star in the heavens a hundred times, for in general if its right ascension was known to within some quarter of a second of time, and its declination to within three or four seconds of arc, that was ample. And this degree of accuracy could be obtained by half a dozen observations or so. Such a catalogue had been published by Lacaille in 1757, the number of stars being 398. In 1803 Piazzi published at Palermo a great catalogue of 6748 stars, and in 1814 a second catalogue of 7646 stars, these catalogues being remarkable for their completeness and accuracy. In 1806, De Zach published a catalogue of 1830 zodiacal stars observed by him at Seeberg in Saxe Gotha. This catalogue was, however, far less accurate than Piazzi's. In 1818 Bessel of Konigsberg published a catalogue of 3112 stars, founded on the observations made at Greenwich between 1750 and 1762, by James Bradley, the then Astronomer Royal. From the skill and care with which these observations have been reduced by Bessel, this forms one of the most accurate and valuable of the earlier star catatogues. Later, Airy undertook the reduction of a great series of observations of circumpolar stars made by Groombridge between 1806 and 1816, and the resulting catalogue of 4243 circumpolar stars was published in 1828. In 1827, the Royal Astronomical Society published a catalogue of 2881 stars, founded on the results given in all the previously published catalogues; and in 1845, the British Association published a similar catalogue of 8377 stars, constituting one of the most valuable in existence. All these catalogues made some pretence to accuracy, and in most cases the star places rest on from six to a dozen observations. But it was soon found that the number of stars which were visible in ordinary telescopes were so numerous that the task of observing them with such accuracy would be out of the question. Yet it was important that the place of all such stars should be determined with such accuracy that the identification of each star could always be accomplished.

Survey of the heavens.

For this purpose, however, it was merely necessary to observe it once or twice. Towards the end of the eighteenth century a great number of such observations were made by D'Agelet and Lalande, and they were published in 1801, but entirely unreduced, so that they were of little use to astronomers. In 1837 the British Association undertook the reduction of these, and in 1847 the resulting catalogue of 47,390 star observations was published. It gives the place of nearly every star down to the eighth magnitude, and the places of many stars of the ninth magnitude. In 1821 Bessel undertook the observation of all the stars down to the ninth magnitude between 15° south declination and 45° north declination. By 1833 the work was completed. Weisse, an

Austrian astronomer, undertook the reduction of the observations, and in 1846 published the result for all the stars within 15° of the equator, it forming a catalogue of 31,895 stars; whilst in 1863 there was published the catalogue of 31,445 stars founded on Bessel's observations of stars between 15° and 45° of north declination. In 1821 Sir T. Brisbane erected an observatory in Australia, at which a number of observations were made. In 1835 a catalogue of 7385 stars was published. Between 1822 and 1843 a number of observations were made at Madras, and in 1844 was published Taylor's catalogue of 11,015 stars, founded on these observations. In 1841 Argelander of Bonn undertook to complete Bessel's work by observing all the stars between +45° and +80° of north declination; but this was subsequently extended into the observation of all the stars down to the 9½th magnitude between 2° of south declination and the north pole.

Founded on these observations, there was published in 1859 a catalogue of 110,984 stars between 2° south declination and 20° north declination; in 1861 a catalogue of 105,075 stars between 20° and 40° north declination, and in 1862 a catalogue of 108,129 stars between 40° and 90° north declination. By means of these great catalogues it is possible to determine the approximate position of every star except the very faintest which is visible in ordinary telescopes.

Star maps.

These determinations of the approximate places of the stars led to a great improvement in the maps of the heavens. Thus, in 1801 Bode published his *Uranographia*, containing twenty maps of the different constellations, and showing some 17,000 stars. In 1822 this was followed by the publication of Harding's Atlas, giving the stars on 27 charts. Between 1830 and 1860, the Berlin Academy issued 24 maps, designed with the view of identifying objects in the zodiac. In 1847 Argelander issued his *Uranometria Nova*, containing 17 charts. Since then a considerable number of other maps have been issued; some, like those of the Bonn Observatory, containing nearly every star down to the 9½th magnitude.

Changes suspected in the moon.

It has been already mentioned that Schröter, who had assiduously observed the moon, had come to the conclusion that considerable changes, probably of volcanic origin, were going on, and gradually modifying the surface of our satellite. His observations led him to believe that several mountains had fallen in great landslips, that four or five craters had suddenly made their appearance owing to volcanic outbursts, and that two or three had as suddenly disappeared, probably from the collapse of their walls. He also had noticed considerable changes in the brightness and colour of different portions of the lunar surface. These things excited much attention, and a lively controversy ensued as to whether he was correct or mistaken in his opinions. Gruithuisen of Munich, a keen but fanciful observer, declared he could discern many facts in support of Schröter's view, and he pointed out some remarkable formations on the lunar surface, which he declared must be artificial, and must be due to the work of inhabitants of the moon. Others, less experienced observers, declared that they could not see these remarkable formations, and did not hesitate to say they did not really exist; but we now know that they were wrong in this, and that these remarkable formations do really exist.

New lunar maps.

During the years 1820 to 1827, Lohrmann, a German amateur astronomer living at Dresden, made many observations of the lunar surface, and carefully measured the exact position of some of the principal points. In 1824 he published four sections of what was intended to be a complete map of the moon in twenty-five sections. These maps were incomparably superior to anything of the kind which had been published before, and enable a true idea to be formed of the real condition of the lunar surface. Lohrmann was never able to complete his design, but the remaining twenty-one sections of his map were completed by Schmidt and published in 1878. From 1830 to 1837 the study of the condition of the lunar surface was assiduously carried on by Mädler, a German astronomer, and in 1837 he published an elaborate monograph on the condition of the lunar surface, accompanied by a most complete map on the scale of 37½ inches to the diameter of the moon.

Real nature of lunar surface.

Mädler in his work gave a critical examination of the views advanced by Schröter, but was unable to confirm them. He showed very clearly that the lunar atmosphere must be much rarer than that of the earth, though he believed he had found evidence that an atmosphere did exist. He also showed that there were no masses of water in the moon, neither sea, river, lake, nor stream, nor were there clouds in the rare atmosphere, nor rain to fall on the arid surface; yet he was of the opinion that it was not unlikely that some moisture might exist within certain of the deeper ring-plains, to be vaporised as the sun rose above the horizon and condensed as a heavy dew after the sun had set. He pointed out that throughout the course of his eight years' observations he had been unable to trace any instance of a great volcanic change, such as Schröter had been led to imagine were frequent in the moon; but he did not lose sight of the fact that were the volcanic energies on the moon only on the same scale as on the earth, it was exceedingly improbable that they could be detected without a much more elaborate and systematic series of observations than even he had been able to give. Mädler also pointed out that many of the instances of supposed variations in brightness which had been referred to by Schröter were probably only apparent; yet he himself pointed to instances where such changes seemed to be really occurring, and suggested that they might be due to some kind of vegetation. In summarising his views on the present condition of the lunar surface, Mädler pointed out how impossible were the views held by the earlier astronomers down to Sir William Herschel—the opinion that the moon might be a mere copy of the earth, with a dense atmosphere, large oceans, abundant vegetation, and numerous varieties of animal life, including even human inhabitants. As he forcibly pointed out, the absence of oceans, rivers, and even rain, the rare atmosphere, the absence of trees and shrubs, all were conclusive evidence that the moon was no copy of the habitable world, but rather resembled some of the rugged, arid, volcanic regions of the earth.

In a condensed and unqualified form these remarks of Mädler's crept into all the text-books of astronomy, and gave rise to almost as false a view of the true constitution of the moon as that to combat which they were originally written; and they had an enormous and unexpected influence on the progress of selenography, or the study of the condition and appearance of the moon. Astronomers, taking their views as to the probable condition of the moon from these remarks of Mädler's quoted in the text-books, regarded it as demonstrated that the moon was to all intents an airless, waterless, lifeless, unchangeable desert, with its surface broken by numerous vast extinct volcanoes.

Moon supposed a desert.

When the astronomer comes to examine the moon with his telescope he finds it present an appearance which seems to be entirely consistent with this prevalent view. Approaching the study of its surface with the strongly preconceived notion that it is a mere arid desert, nearly red-hot at times from the heating effects of the sun during the long cloudless day of some three hundred and fifty hours, and almost immeasurably cold at others from the night of similar period, without water, air, or life, the real condition of the moon is not such as to dissipate these views at the first glance. Its cold, still, apparently unchangeable surface, so utterly unlike what the earth might be supposed to appear as seen from the moon, convinces the casual observer that the world he there sees is utterly unlike the world he knows. He looks for immense cloud-masses floating in a dense atmosphere, and he sees none; he seeks for wave-tossed seas, for calm mirrored lakes, for broad winding rivers, or for rushing, roaring streams, but there are none; he searches for luxuriant forests, for wide purple heaths, for sunny green meadows, and lo! they are absent. This is enough, and he retires from the further contemplation of the "airless, waterless, lifeless, volcanic desert" of the text-books of astronomy. During subsequent periods he may again take a casual glance at our satellite, look at the occultation of a star by the moon, or watch the grand changes in appearance that the face of the moon presents as the sun sweeps slowly across its heavens, and gradually illuminates in turn its manifold varied features. Or perhaps, hearing of reported changes on the lunar surface, he takes some opportunity for watching its surface for a few evenings. He looks here, there, and everywhere, for a huge flaming volcano, scrutinises in turn each of the great walled plains of the moon, with their yawning mouths fifty miles in diameter, to see if one or more is vomiting forth fire and ashes, and discharging immense lava streams on to the surrounding surface. But he sees none. He looks at some of the immense mountain peaks which tower twenty thousand feet above the surrounding surface, to see if any have come crashing down, covering all around with ruin and *débris*, but he sees all unchanged. He searches to see if perchance some new crater has made its appearance during the night, and lies there with its newly-formed yawning mouth miles in width and thousands of feet in depth; but he sees none. Where are, then, all these changes that they talk about? He sees none; there are no changes occurring—all volcanic energy must be extinct. So he retires in disappointment that the moon should not show such terrific manifestation of volcanic forces in every month in the year, though he

No apparent lunar changes.

has been searching for things which have not occurred on the earth for untold centuries. Yet the terrestrial volcanic energies are far from extinct.

Views held by selenographers.

But an entirely different opinion is held by those astronomers who have systematically studied the lunar surface—who, by assiduously piecing together, bit by bit, all the varied information which is revealed as the moon passes through its varied aspects, have been able to obtain a true conception of the real nature of the different lunar formations. They look for the changes on the lunar surface amongst the smaller features, where such changes may be supposed to be occurring at wide intervals, and do not hunt for craters with yawning mouths fifty miles in diameter, nor expect to find immense mountain masses, miles high and wide and long, tumbling down in all directions. They see that the extinct volcanoes of the ordinary observer are really intersecting masses of mountains, and bear no analogy to the true terrestrial volcanoes. They seek for instances of changes in the surface of the moon, for landslips, for avalanches, and they find instances where such have occurred in recent times. They look for cases where portions of the steep walls of the lunar ring-plains have fallen with terrific energy into the interior, filling it up with ruins and *débris*, and they find instances. They search for the representatives of the terrestrial volcanoes, and they find them much resembling those on the earth. These they critically watch, and have found more than one case of suspected change in them, whilst at least two new ones have made their appearance. They seek for changes in the tint of the lunar surface, such as might be caused by some kinds of vegetation, and they find large tracts undergoing periodical changes in colour as the lunar day progresses, and exactly corresponding to the changes which would be visible from the moon in the more arid portion of the earth as vegetation gradually waxed and waned with the seasons. And thus they are led to believe that the moon is far from being the unchangeable arid volcanic desert of the text-books. It is no copy of the earth, but the differences are merely in degree, not in kind.

Improvements on the Lunar Theory.

Whilst astronomers were occupied in accurately observing and mapping the surface of the moon, others were no less busy in perfecting the theory of the motion of our satellite. From 1828 to 1831 Plana, an Italian mathematician, was engaged on an elaborate research on the lunar theory, endeavouring to investigate the theory with such care and minuteness that lunar tables could be constructed purely from theory. With considerable ingenuity he introduced many simplifications and improvements, and carried his results to a far greater degree of approximation than had hitherto been done. In 1831 the results of his investigation were published in three large quarto volumes at Turin, and constituted a great advance in our knowledge of this difficult branch of mathematical astronomy. Between 1833 and 1838 Pontécoulant, a French astronomer, undertook a similar investigation of the lunar theory, but by a different method, and obtained results which practically confirmed those found by Plana. There only remained a number of small discrepancies between the two. The origin of these was investigated by both Pontécoulant and by Sir John Lubbock, who succeeded in removing the greater number by detecting small errors in the numerical results of Plana. The origin of others they were unable to find out. Thirty years later Professor Cayley, of Cambridge, discovered that a small but accidental error had been made by Plana at the very beginning of his labours, where neither Plana, Pontécoulant, nor Lubbock had suspected one could exist. When this error is corrected the results found by Plana and Pontécoulant may be said to be in perfect accord. Subsequently tables were constructed in America on the basis of these investigations, and they were found to represent the motion of the moon with very considerable accuracy, the error seldom amounting to half a second of time.

Hansen, a German observer, devised a new method of investigating the lunar theory, using a numerical process, and this theory he brought to a successful conclusion. He also constructed elaborate tables founded on this theory, and these tables have been found more perfect than any others, and are now in general use. Hansen also discovered several small inequalities in the motion of the moon which had been overlooked by others. He likewise showed that the planet Venus would exert a considerable effect on the motion of the moon, partly by its direct attraction, and partly by its indirect effect in modifying the orbit of the earth. The former conclusion of his has been questioned by several astronomers, and the whole subject is still uncertain.

The Sun.

During this period little further advance was made in our knowledge of the constitution of the sun. From time to time observations were made of the sun-spots which were visible on its disc, but these observations led to little real advance in knowledge of the true character of the central body of the solar system. It began to be understood that the sun was an intensely heated body, probably surrounded by a dense uncondensed atmosphere, and that the spots were depressions in this gaseous envelope, and being cooler, emitted less light and so looked dark. It began to be suspected, too, that these spots, which were very variable in number, might be periodical in their variation. Schwabe, a German amateur astronomer, determined to ascertain if this were really so. Between 1825 and 1830 he had frequently observed and drawn the spots visible from day to day upon the sun; but in 1830 he commenced a most systematic watch, observing and delineating the position of the solar spots on every day that the sun was visible—usually about 300 days in each year. These observations he kept up for a period of over thirty years. Before long he convinced himself that this periodicity in the number of solar spots visible was a reality, and that every ten years the number of spots rose to a maximum and sank to a minimum. At the time of a sun-spot minimum many days might elapse without a spot being seen, and perhaps the total number of groups of spots visible in the year would be only a score or two; whereas at the time of a sun-spot maximum on every day the sun appeared with several groups of spots on its disc, and the number of groups of spots discovered in the year would amount to several hundreds. Subsequent researches seemed to show that the period of this sun-spot variation was nearer eleven years than ten, and was probably somewhat variable.

Observations of total solar eclipses.

Considerable attention was paid to observations of the total eclipses of the sun, and a considerable number of interesting but perplexing facts began to be discovered, or rather became known, for it was subsequently found that many of the phenomena detected during the observations which were made at this period, and which excited so much attention, had also been observed at earlier periods, but had been overlooked or misunderstood. The most famous of these eclipses was that of 1842, which was observed by the most celebrated astronomers of the day, and was visible in the south of France and north of Italy. Round the dark moon was seen the usual bright radiance, resembling the glory seen round a saint's head in the mediæval pictures, which is now called the *corona*; but close to the moon there were noticed projecting from it a number of pink or red prominences like flames, some of them more than a tenth of the moon's semi-diameter in length. Again, just before the eclipse ended, there appeared on the border of the dark moon a number of very bright spots of light—Bailey's beads, as they were termed. The corona, too, was seen by several observers to flicker, or vibrate, and when closely observed it was seen to have a radiated structure with an irregular outline, and to be far from being a mere whitish ring round the sun. All these curious phenomena lent interest to the observations of total solar eclipses, and promised to throw much light on the constitution of the sun, for it became gradually recognised that these must be phenomena appending to the sun; though certain astronomers were inclined to ascribe the origin of some to the moon, and of others to the terrestrial atmosphere. But whilst all these observations seemed to afford valuable clues to important discoveries in solar physics, still up to this time little real advance had been made in our knowledge of the true character of the sun.

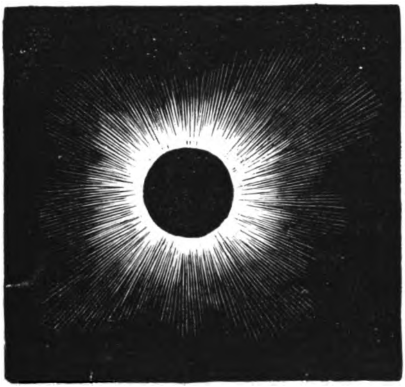


FIG. 40.—SOLAR ECLIPSE WITH CORONA.

During the first half of the present century little progress was made in our knowledge of the two inferior planets Mercury and Venus. Schröter had believed he had detected spots on both these planets, and from certain irregularities in the terminator, as it is called—that is, the border line between the illuminated and unilluminated portions of the planet—he believed that there must be exceedingly lofty mountains on both planets.

Mercury.

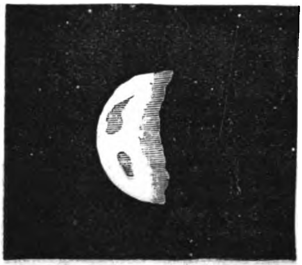


FIG. 41.—VENUS, AT QUADRATURE.

Later observers have failed to obtain any strong confirmation of these features. Both Mercury and Venus are seen to have their illuminated portion slightly less than what it should theoretically be, and this has been regarded as evidence of both possessing dense atmospheres. Further evidence of the existence of these atmospheres is seen in the ring of light surrounding the planet at the moment it is entering on or leaving the sun during its transits. This was very noticeable in the transit of Venus during the last century, and was confirmed by the observations made during the first transit of this century. Further, Mädler noticed that when the planet Venus was very near its inferior

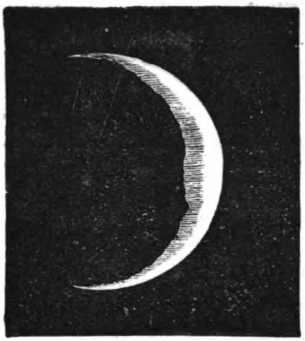


FIG. 42.—VENUS, NEAR INFERIOR CONJUNCTION.

Atmosphere of Venus.

conjunction, and was passing between the sun and the earth, the illuminated portion of the planet exceeded half the circumference, owing to the horns of the planet being prolonged. From the amount of this prolongation Mädler calculated that the atmosphere of Venus must be half as dense again as our terrestrial atmosphere. De Vico, of Rome, between 1839 and 1841, made a number of observations of the appearance of Venus, and detected a number of faint spots on its surface. From these he concluded that Venus rotated on its axis in 23 h. 21 m. 22 s. Later observers have not been so successful in observing these spots on Venus, and some doubt attaches to their reality. We may hope, however, to have the matter cleared up one of these days.

Further observations of Mars.

The planet Mars had also been carefully studied by the German astronomer Schröter, but his drawings were never published. He found reason to believe that the spots on Mars varied rapidly, and therefore were probably in great part due to clouds. Mädler undertook the further examination of this subject, and between 1830 and 1841 made very numerous drawings. He found that the principal spots were permanent markings, but that from time to time they seemed temporarily obscured. Later observers completely confirmed this, and Mars has been carefully mapped in the same manner as the moon. They consist of numerous greenish-grey spots on an orange-yellow background, and there is reason to believe that the former represent the seas on Mars and the latter the land. From time to time whitish spots, seemingly clouds, prevent the dark spots from being clearly seen. At the poles are white spots, which have been thought to be polar snows, as they seem to grow smaller in the Martial summer and larger in the winter. The drawings of Mars made at this period are generally rather rough.

Spots on Jupiter.

Little further advance was made in the observations of Jupiter, though a number of drawings of the beautiful belts were made. The most noteworthy features discovered were the existence of both white and dark spots of temporary character on these belts, which were themselves variable in number, position, and distinctness. It began to be gradually understood that what was seen in the telescope was probably only the upper cloud-bearing strata of Jupiter's atmosphere, so that much permanence could not be expected in the details visible. From the observation of a spot, Airy, in 1834, determined the time of rotation of Jupiter on its axis to be 9 h. 55 m. 21 s. Mädler makes it 9 h. 55 m. 30 s.

Saturn's rings.

With regard to Saturn, the other giant planet of our system, a considerable amount of additional information was obtained. Schwabe, who was an excellent observer, drew attention to the fact that Saturn was not placed in the centre of its rings, but was nearer the west than the east side of the rings. Subsequently it has been shown that this eccentricity is essential for the stability of the ring system, which would otherwise be brought crashing down on to the surface of the planet from the influence of its attraction. It also appears, from theoretical considerations, that the ring of Saturn must be in rapid rotation round the planet—a circumstance confirmed by observations which have been made of the apparent

Discovery of a new ring.

Divisions in the rings.

motion of some small irregularities in the ring. In 1838, Galle, of Berlin, when observing Saturn, noticed a third ring, much fainter and duskier than the other two rings, and lying within them, or between the planet and the innermost of the old rings. He carefully measured the ring, and published his important discovery. Yet it did not attract the slightest attention, and fell into complete oblivion: probably because neither Herschel, nor Schröter, nor Struve, all of whom had most carefully observed Saturn, had seen a trace of such a ring: it was therefore regarded as some mistake. There were, moreover, few telescopes in those days of sufficient size and quality to settle such a disputed point. Twelve years later, however, Bond in America, and Dawes in England, independently rediscovered this ring, when the discovery excited great interest. Every large telescope was at once turned on Saturn, and the existence of the ring at once established. Reference then showed that it had been also seen by Galle twelve years earlier. This inner ring is now known as the crape ring. It is not a difficult object for a telescope of five or six inches aperture; and it is not easy to understand how it was overlooked by Struve, when measuring the rings in 1826. The figure (fig. 43) will give some idea of Saturn with its three rings and belts; it is, however, coarsely drawn, and the distinctness of the different features enormously exaggerated To a certain extent, however, this is inseparable from a woodcut. The outermost ring is called A, that next to it B, and the innermost, or crape ring, C. The two outer rings have by several observers been seen broken up by fine lines into a number of smaller concentric rings; but it is doubtful how far this appearance is real. It is probable, however, that the outer ring, A, is really divided into two narrower ones by a dark line, called Encke's division, from its discoverer. At one time it was thought that Saturn's rings were gradually widening, the outer edge increasing in its distance, and the inner edge decreasing in its distance from the planet, so that before long the inner ring would fall upon the planet. Later measures have shown that this is not really the case, and that the apparent alteration was due to the imperfections in the earlier measurements.

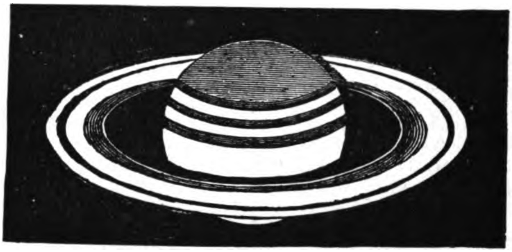


FIG. 43.—SATURN.

In September 1848, Bond of America and Lassell of Liverpool discovered an eighth and very minute satellite to Saturn. Hyperion, as it is called, is very faint, and lies between Titan and Iapetus, its distance from the planet being twenty-six semi-diameters of Saturn, and its period of revolution about 21⅓ days. It is not improbable that there are other minute satellites in the wide interval between Titan and Iapetus; but from their distance from the planet, and their minuteness, they are so difficult to distinguish from faint stars that their discovery must be a work of much trouble and labour.

Discovery of a new satellite.

Uranus continued during this period to remain a perplexity to astronomers. Its small size rendered all scrutiny of its physical aspect nugatory; nothing new was discovered; it shone as a little round disc of pale bluish light. Several observations were obtained of its two faint satellites, but there were few telescopes sufficiently powerful to show them. From Sir John Herschel's observations, it appeared that the outer satellite called Oberon, was distant from the planet by 22¾ radii, and revolved round it in 13½ days. The inner one, named Titania, was distant by 17 radii, and its period was only 8¾ days. No trace was seen of the four other satellites which were suspected by Sir William Herschel. In September 1847, Lassell discovered another but much fainter satellite. It was very close to the planet, being only distant 7½ radii of Uranus, and only requiring 2½ days to revolve round it. This satellite was called Ariel. In the following October, O. Struve, of Pulkowa in Russia, discovered another satellite, called Umbriel: its distance from Uranus is 10⅓ radii of the planet, and its periodic time 4⅛ days. When first discovered these satellites were regarded as identical, and much perplexity arose in consequence, as the observations could not be reconciled with each other. As they were both exceedingly faint objects, much fainter than the two others, there were only three or four telescopes which would show them, consequently the observations were very few and very uncertain. Gradually, however, it began to be recognised that the observations could not be reconciled, so that there must be two satellites. Subsequent observation confirmed this, as both were seen together.

Satellites of Uranus.

Discovery of new satellites.

It was the erratic motion of Uranus which was so perplexing to astronomers. It has been already mentioned that Bouvard found himself unable to reconcile the theory of the planet with both the early and more modern observations, so that he founded his tables on the latter only. These tables, however, soon began to fall into great error, and much speculation arose as to the cause of the discrepancy between the observed and tabular motion of the planet. It soon began to be suspected that the cause must be the attraction exercised on Uranus by some unknown planet lying beyond it; and between 1833 and 1840 this idea began to receive general acceptance amongst astronomers. To believe in the existence of the planet, and to discover its whereabouts, however, were two very different things. Dr. Hussey suggested sweeping the heavens for the body with large telescopes, but it was soon seen that this would be out of the question.

Anomalies in motion of Uranus.

New planet suspected.

It was unlikely that the new body would be brighter than a star of the ninth magnitude; and there are so many stars of the ninth magnitude which might prove to be the planet—probably some thirty thousand—that it would be utterly impracticable to attempt to examine each to see if it was moving. If, then, there were such a planet disturbing Uranus, where would it be? in what part of the heavens would it be found? If that were known, then it would be possible to search that small part of the heavens, and to examine each of the four or five hundred stars contained in it to see if one was moving, though even then the work would be laborious.

In 1842, Bessel, one of the greatest German astronomers, and a profound mathematician, determined to investigate this problem, and see if from the anomalies in the motion of Uranus he could not determine the position of the unknown planet which had given rise to them. He gave instructions, therefore, for the complete reduction of all the observations of Uranus, so as to have the requisite data for his mathematical calculations. Bessel's death, however, put a stop to all, and no other astronomer with the requisite skill seemed to have the necessary time for the undertaking. Adams, a young Cambridge mathematician, who had graduated as senior wrangler in 1843, was the next to undertake the work. He first of all ascertained, by a new investigation of the perturbations of Uranus, that it was not possible for the anomalies to arise from an erroneous theoretical determination of these perturbations. This he proved to be the case, for though he discovered some errors, he found that they were of a kind which did not materially reduce the known anomalies in the motion of Uranus. There could be no doubt, therefore, that there must be some unknown body, some new planet, whose attraction was disturbing the motion of Uranus. After an elaborate mathematical investigation, in the autumn of 1845 Adams arrived at the conclusion that if there were a planet, whose mass was $\frac{1}{3000}$ of that of the sun, and its mean distance 38·4, with an orbit of given excentricity and position, it would exercise a disturbing action on Uranus which would explain all the known anomalies in its motion. This result he communicated to the Astronomer Royal, pointing out what would be the position of the planet in the heavens during the year. Beyond acknowledging the receipt of the communication and asking a question, the Astronomer Royal took no further steps in the matter; and so the result rested unknown and unpublished to the scientific world.

Investigation of its probable place.

Adams' results.

In the same autumn, Leverrier, a young French astronomer, undertook the investigation of the same problem, and proceeded in his labours in a most detailed and satisfactory manner. He first elaborately investigated the theory of Uranus, taking into account in the most complete manner the perturbations produced by the two giant planets Jupiter and Saturn. The results of this investigation he published in November, 1845. He next proceeded to reduce all the observations of Uranus, and compare them with the theory as amended and improved by him; and he found that there remained errors which could not be explained by any amendments in the theory of Uranus, unless there were some unknown body disturbing its motion. Investigating every possible hypothesis, he showed that this body must be a large planet beyond Uranus, but not very far beyond,—probably about as far beyond Uranus as Uranus was distant from the sun. If there were such a planet, then Leverrier pointed out that its existence would render it possible to account for all the anomalies in the motion of Uranus. If such a planet did exist, whereabout in the heavens would it be situated?—that was the next question. Leverrier's answer was clear and explicit. On January 1st, 1845, it would be in longitude 325°, or within some 10° of that longitude. This was clear and satisfactory enough. On the same day Adams' investigation would have given the place 328°, or almost identically the same. These results were published in June 1846. This now aroused the attention of the Astronomer Royal, and at his suggestion the great equatorial of the Cambridge Observatory was employed to search in this part of the heavens for the suspected planet, and on the 29th July, 1846, the search was commenced. In the meantime both Adams and Leverrier had proceeded with their investigations. His later results now led Adams to believe that the planet was much closer to the sun than he had previously found, and had a somewhat smaller mass. The result was, however, the same—the planet would be in the same part of the heavens, and almost in exactly the same place. Leverrier continued his researches, and at the end of August 1846 they were published. He now gave the values he found for the elements of the orbit of the new planet—elements in perfect accord with those found by Adams, but still unpublished. But, not content with pointing out the exact place of the new planet, Leverrier proceeded to inquire as to what would be its probable appearance. He showed, from its probable mass and distance, that if it had a

Leverrier's results.

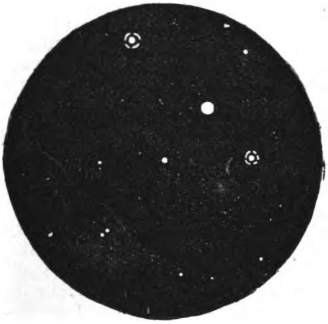


FIG. 44.—NEPTUNE IN FIELD OF VIEW WITH STARS OF 6TH, 7TH, 8TH, AND 9TH MAGNITUDES.

Search for the suspected planet.

Its probable appearance.

Discovery at Berlin.

density similar to Uranus, this new planet would have a diameter of about 3·3″. It would shine like an eighth magnitude star, and be distinguishable from the other stars by having in a good telescope a sensible planetary disc, and not appearing like a very minute point of light. As Leverrier pointed out, this is a most important result, for instead of having to determine the places of some four or five hundred stars on different days, and then compare the observations on separate nights in order to see if any of the stars were moving, his investigation indicated that the planet could be distinguished from all the other bodies of the same magnitude by its having a sensible planetary-looking disc. Leverrier wrote on the 18th September, 1846, to the observatory at Berlin, asking them to search for the new planet. On the 23rd the letter reached them, and on the same evening Dr. Galle turned the telescope on the heavens and looked in the place assigned to the new planet by Leverrier. There was no suspicious-looking star to be seen. On searching for a little distance on either side, he saw a big-looking star about a degree in advance of the place assigned by Leverrier. It looked of an abnormal size. Closer inspection showed it had a small disc about 3″ in diameter, whereas the other stars had much smaller discs. The astronomers at the observatory looked therefore into a map of this portion of the heavens which they had only just completed. No such star was visible. Had they then discovered the planet? The next day settled the matter: the star had moved more than a minute of arc. It was the new planet. Mathematical analysis had won one of its grandest triumphs, and astronomy had achieved a glorious advance.

Neptune.

The discovery excited much interest, and gave rise to a long discussion as to which astronomer had the claim to priority; but astronomers are now content to assign to each full credit for the magnificent work done by him. Search made in the earlier star catalogues revealed the fact that the new planet had been observed as a fixed star on several previous occasions, and on two occasions by Lalande in 1795. On computing the elements of the new planet, it was found to move in a very different orbit to that assigned to it by the investigations of Adams and Leverrier; but this is not surprising, for all that these researches could do was to determine the position of the small arc of the orbit of Neptune in which it was moving when it exerted most influence on Uranus, and to fix its place in this arc of its orbit. More than this could not be done; and by suitably altering the elements of the orbit, an innumerable number of orbits of different dimension can be found to approximately fulfil these conditions.

The new planet was named *Neptune*, after a somewhat long discussion. Its mean distance was found to be about thirty times the mean distance of the earth, so that it takes 164¾ years to make one complete revolution in its nearly circular orbit.

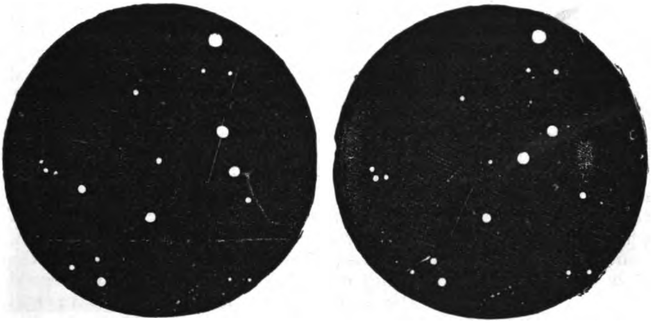
Appearance of Neptune.

On the discovery of Neptune, the larger telescopes were directed to a close scrutiny of the physical appearance of the new planet. Nothing was made out beyond the fact that it shone like an eighth magnitude star, and appeared like a tiny bluish disc about 2½″ in diameter. It had a real diameter, therefore, of 36,000 miles, which is somewhat greater than that of Uranus, and its mass was found to be also a little larger. Neptune therefore, takes rank as the third largest planet of our solar system.

On October 10th, Lassell, who was observing the planet with his large reflector, observed a faint star near Neptune which seemed to follow it. He suspected that it was a satellite, but the approach of the planet to the sun put a stop to further observations. Next year he again sought for this suspected satellite, and in the beginning of July rediscovered it. It was subsequently observed by Otto Struve in Russia, and Bond in America. It is a very faint body, but not nearly so much so as the inner satellites of Uranus. It takes some six days to revolve round its primary, and its mean distance is about thirteen times the radii of the planet.

Discovery of a satellite.

Although it was generally believed that there must exist a number of undiscovered minor planets, for many years after Olbers' discovery of *Vesta* no further attempt was made to discover them. Nor was this surprising: if it had taken Olbers, with all his experience, three years to discover Vesta after the discovery of Juno, it was probable that it would be seven or eight years before any one else succeeded in discovering one. To devote so much time for so uncertain reward was not promising, so no wonder astronomers were not tempted. The resolution of the Berlin Academy to undertake the construction of a series of equatorial charts, showing all the stars down to the tenth magnitude, rendered the search for other minor planets more promising, for to discover such a planet it would only be necessary to compare these maps with the heavens, so as to see if there were any star visible which was not on the map. In 1830, therefore, Hencke, a German astronomer, undertook the renewed search for these bodies. Day after day went by without result; year followed year, and still his labours



Dec. 8th. Dec. 9th.

FIGS. 45 AND 46.—FIELD OF VIEW SHOWING MOTION OF MINOR PLANETS AMONGST THE STARS.

Further search for minor planets.

Discovery of one.

were unrewarded. Those who anticipated that an observer might search for seven or eight years without discovering a new planet turned out to be correct, for eight years went by and brought the patient observer no return for all his labours. Ten years went by, but still no result; fifteen years went by, and no discovery had yet rewarded him. Still the indefatigable observer persevered. At last, on the 8th December, 1845, he noticed a star where he was sure there had been none when he had observed this region on a previous day. He wrote to Encke of the Berlin Observatory, announcing his discovery of a suspected planet. The truth of the discovery was confirmed on the night of December 14th, and Europe was surprised by the announcement of the discovery of yet another minor planet. The new comer was named *Astræa*. It shone like a star of 8½th magnitude, so it was much fainter than the four discovered in the beginning of the century.

Hencke discovers another.

Further discoveries.

The immense time it had taken Hencke to discover this single new planet was enough to deter others from searching for still more. But an unexpected revelation was coming. On the evening of July 1st, 1847, Hencke discovered a star of the ninth magnitude not shown on the Berlin star map, and on the 3rd he found that this star had moved very considerably. There could be no doubt it was yet another minor planet. He speedily announced his discovery, and the new body was named *Hebe*. This second discovery so soon after the first led to others taking up the same search. Only a few days flew by when, on August 13th, Hind, a young astronomer observing at the Regent's Park Observatory, belonging to Mr. Bishop, discovered a third new minor planet, a body christened *Iris*. Two months later, on October 18th, Hind discovered yet another, that now named *Flora*. These discoveries illustrated the ease with which these bodies could be discovered now that good charts of the heavens had been constructed; and before the beginning of 1850 two more were discovered—namely, *Metis*, by Graham, at Col. Cooper's observatory in Ireland, and *Hygeia* by De Gasparis, at Naples; making ten in all.

The orbits of all these minor planets were speedily determined, and they were found to have the same character as those of the four discovered early in the century, only they were smaller and fainter, shining like stars of the eighth and ninth magnitudes; whilst all were lying close together in a narrow zone between Mars and Jupiter. Their discovery seemed to lend additional probability to the hypothesis of Olbers, that they were the fragments of one large planet.

Comets of short period.

In other branches of astronomy little that was of new character was accomplished; what was done was mainly to perfect those discoveries which had already been made. Many observations were made of comets, including the very brilliant comets which appeared in the years 1811, 1819, 1835, and 1843. The orbits of a great number of comets which had appeared during this period—some ninety in all—were carefully computed. In this manner it was soon discovered that a number seemed to have elliptic orbits of quite short period; and Encke, a German astronomer, pointed out that the comet of 1818 moved in an elliptic orbit of only 3½ years period, and was a reapparition of a comet which had been seen in 1805, and before that in 1795. He calculated that it should reappear in 1822, though it would only be visible in the southern hemisphere, and in 1825. It was seen on both occasions, and since then has been seen on each of its numerous reappearances. Subsequently other periodic comets were discovered, until now a tolerable number of comets of short period are known, and regularly return at their predicted times. In 1835 Halley's comet made its predicted return, and the theory of its motion was so accurately investigated, that it returned to perihelion within three days of the predicted time.

Halley's comet.

Much attention was also given by astronomers to cataloguing all the nebulæ and double stars which could be discovered, and in the case of the double stars carefully measuring their distances and position angles. It was soon found that many of these double stars were binaries, or were revolving round their common centre of gravity. The orbits of many of these were calculated, and found to agree moderately well with the observations.

Double stars.

Much attention was also given to determining more accurate values of the numerous astronomical constants requisite for properly reducing the observations which were made—such as the constant of aberration, the value of the constant of precession, nutation, refraction, etc. These were soon determined with great care and accuracy.

Astronomers then devoted their attention to improving their instruments; and better forms were devised for transit instruments, mural circles, and transit circles which form a combination of the two last, and enable both the right ascension and declination of a heavenly body to be determined with the same instrument. Telescopes were also improved and the art of manufacturing object-glasses for telescopes made great strides, so that refracting telescopes with apertures of six and nine inches became not uncommon, whilst several were made with apertures of from eleven to fifteen inches. All these improvements contributed materially towards the rapid advance that astronomy was destined to make in the third quarter of the present century.

Improvements in instruments.

When the different accurate catalogues came to be compared, it was found that some of the stars had undoubtedly a proper motion of their own, independent of the slow motion they had all in common from precession. This had been suspected by the earlier astronomers, but they had been unable to satisfactorily verify it. In some cases these proper motions were very considerable. Thus there are two faint stars in the southern hemisphere which were suspected to move over nearly 8″ per annum; whilst 1820 of Groombridge's Catalogue moves nearly 7″ per annum, and 61 Cygni, a fifth-magnitude star, moves more than 5″ per annum. All these are faint stars. The brighter stars have generally much smaller proper motions.

The improvements introduced during this period into the construction of astronomical instruments, and the greater accuracy with which had been determined the different astronomical constants which enter into the reduction of all observations, seemed to render it possible that the parallax of some of the bright stars might now be determined; and so afford astronomers some definite knowledge of the dimensions of the greater solar system—that is, the system of stars of which our sun is one. During the early part of the century, Piazzi and Calandrelli, two Italian astronomers, endeavoured to determine the parallax of some of the brightest stars, such as *Sirius* and *Vega*, by comparing their declinations as measured with an alt-azimuth instrument. They found that these stars seemed to have parallaxes of from 3″ to 4″. But the different results were so discordant that very little confidence was placed in them. Later Brinkley also endeavoured to determine the parallax of a number of stars with the great alt-azimuth of the Dublin Observatory, and found that some of the principal stars appeared to have parallaxes of from 3″ to 4″. Pond, the then Astronomer-Royal, denied the accuracy of this conclusion, for he found that the Greenwich instruments gave no such results. We now know that in this he was correct, for none of these stars have parallaxes of even a tenth of this amount. In fact, the method followed—that of comparing the declination of the star at different times of the year—is now known not to be sufficiently accurate for this delicate purpose.

Struve, of Pulkowa, in Russia, introduced the system of attempting to ascertain the parallax by measuring with a micrometer the distance of some bright star from some faint star very close to it arguing that the parallax of the faint star would be probably insensible, as it would be probably far more distant from us than the brighter star. In 1835 he carefully observed *α* Lyræ in this manner, and found that its parallax was only 0·26″. In 1837 Bessel determined to try if 61 Cygni had a sensible parallax, for though a star of only the fifth magnitude, it had a considerable proper motion of its own. By 1840 he had finished his observations, and, on carefully reducing the different measures and comparing them together, found that 61 Cygni most undoubtedly had a parallax of very near to 0·348″. Subsequently Peters found from a similar series of observations 0·349″. But this was quite eclipsed by Henderson, who, on reducing the observations made by himself at the Cape of Good Hope, found that the bright southern star, *α* Centauri, had the great parallax of 1·16″. Afterwards, Maclear, from later observations at the Cape, found the value 0·91″. This is the largest stellar parallax yet found. Several other stars are known to have a sensible parallax, but most stars have a parallax which is certainly less than 0·1″. Light must take, therefore, many years to come from these stars; and even in the case of *α* Centauri must require more than 3½ years to reach the earth. It is noteworthy that the brightness of a star is no certain criterion of its distance, for, with the exception of *α* Centauri, the six stars which have the greatest parallax are all faint stars.

With the beginning of the year 1850, we propose to end our historical account of the progress of astronomy, for it would be inconvenient to carry it on up to the present time, partly from the great number of discoveries which have been made of late years, and partly because it would interfere with the second portion of our account of astronomy, the part to be devoted to a systematic description of our present knowledge of the science.

PART II.

CHAPTER XI.

THE SOLAR SYSTEM.

Planets and Satellites—The Major Planets—Planetary Moons—The Minor Planets—Intra-Mercurial Planets—Meteors—Meteoric Showers—Astronomical Calculations.

Planets and satellites.

THE solar system may be regarded as consisting of a great number of bodies of very different dimensions moving round the sun in elliptical orbits at different distances and at different velocities. Some of these bodies are known to be accompanied by lesser companions, which move round them as they revolve round the sun. These secondary bodies are known as the satellites, and are comparatively few in number.

The major planets.

The most massive of these bodies which revolve round the sun are known as the major planets, and at the present time eight are known. We say at the present time eight are known, because a century ago there were only six supposed to exist, Saturn being thought to be the outermost planet; yet since this two others have been discovered—Uranus beyond Saturn in 1781, and Neptune beyond Uranus in 1846—so it is by no means certain that there are not other planets beyond even Neptune. Indeed, some evidence has been advanced by astronomers for believing that other planets do exist beyond Neptune. As these planets would shine like very faint stars and move very slowly, they could only be detected with great difficulty, so that if they exist many years may elapse before they are discovered. The eight known planets are called Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune. They may be divided into two groups of four each, the four inner planets, Mercury, Venus, Earth, and Mars, being known as the smaller planets, and ranging in diameter from 3000 to 8000 miles; and the four outer or giant planets, being Jupiter, Saturn, Uranus, and Neptune, with diameters which range from 30,000 to over 80,000 miles, or ten times as great as those of the four inner planets. These eight planets move round the sun in orbits of the form of ellipses whose eccentricity is so small that, except in the cases of Mercury and Mars, the two smallest of the eight, they are nearly circular. Even in the case of these two exceptions the eccentricity is not large enough to show any marked deviation from a circular form. The orbits of these planets are in all cases only slightly inclined to the plane of the ecliptic or orbit of the earth.

Moving round these planets, in the same manner as the planets move round the sun, are other smaller bodies known as the satellites or planetary moons. At the present moment twenty of these moons are known. One revolves round the earth, two move round Mars, four belong to Jupiter, eight to Saturn, four to Uranus, and one to Neptune. It is very probable that in course of time a number more of these satellites may be discovered, for we know they are very variable in size, and the smaller ones would be very difficult to discover. Thus the two small moons belonging to Mars were only discovered in August 1877, having escaped detection, though they had often been looked for, because they are so small. The greater number of the known moons are of very considerable size. Thus the moons of Jupiter are as large as our own moon, and as big as the smaller planets Mercury and Mars. The two principal satellites of Saturn and of Uranus, and the satellite of Neptune, are probably fully as large as those of Jupiter. Five of the remaining satellites of Saturn and the two smaller satellites of Uranus are much smaller—probably only about one-third of the diameter of our moon, or about one-thirtieth of the bulk. The smallest known satellite of Saturn is probably still smaller—perhaps only one-tenth of the diameter of our moon or one-thousandth of the bulk. Finally, the two recently discovered satellites of Mars are much smaller still—perhaps only one-hundredth of the diameter of our moon, which would make their bulk less than one-millionth. If any of the other planets have satellites as small as those of Mars, it is very unlikely that they will be discovered for a very long time, for they would be so faint that the most powerful telescopes would be required to see them.

Planetary moons.

The next class of bodies moving round the sun are known as the minor planets, or, as they are sometimes called, the asteroids. They form a great group of small planets moving round the sun between the orbits of Mars and Jupiter. The first of these bodies was discovered at the commencement of this century, and up to the present time nearly two hundred have been discovered. These minor planets are all very much smaller than the smallest of the major planets, for the largest of the group is not one-twentieth of the diameter of the earth, and possesses not one-ten-thousandth of its bulk, whilst the smaller ones are probably less than one-fiftieth of the diameter or one-hundred-thousandth of the bulk of the larger ones. It will be seen, therefore, that the smaller of the minor planets are very small bodies indeed—in fact, only five or six miles in diameter. Nevertheless, even these small planets probably have a mass of thousands of millions of tons. These minor planets move round the sun in exactly the same manner as the larger ones, and possess orbits of the same form, though the eccentricity and inclination of these orbits are often very considerable. No satellites have been discovered moving round these minor planets; and this is not surprising, for it would be very difficult to see so small a body as the satellite of a minor planet must necessarily be.

The minor planets.

Of late years indications have been discovered of the existence of a similar belt of small planets, moving round the sun within the orbit of the planet Mercury. On several occasions minute round, dark bodies like miniature planets have been seen to cross the sun in a direction and at a rate which would indicate that they were intra-Mercurial planets, moving round the sun in orbits about half-way between the sun and Mercury. Lately, likewise, during solar eclipses bright planetary-like objects have been seen near the sun, shining like stars of the 3rd or 4th magnitude, in places believed to be different from the places of any stars of similar brightness. These bodies appear to be considerably smaller than the planet Mercury, perhaps scarcely a third of the diameter of that planet, though slightly larger than the largest of the group of minor planets moving in orbits between those of Mars and Jupiter. There may be many much smaller than these: they have been suspected to exist, and from their close proximity to the sun, it would be very difficult to detect them.

Intra-Mercurial planets.

A third class of bodies moving round the sun are distinguished by their enormous number and very minute size. The vast majority of them are much smaller than a cricket-ball, a very small minority may be as large as a foot-ball, and it is possible that there are a very much smaller number still that have a diameter of a few feet. The mass of the largest of these bodies is therefore many million times less than that of the smallest of the minor planets. Many of these minute bodies rush through the atmosphere of the earth, and by the friction against the air become white-hot, so that they can be seen. They are then called *meteors*, and now the name is applied to the whole class. It has been estimated that these meteors are so exceedingly numerous that the earth in its daily motion intercepts more than a thousand, mostly of the smallest dimensions. They move round the sun in elliptical orbits like the planets, but instead of these orbits being very nearly circular, there is reason to believe that many of them move in orbits of great eccentricity—orbits that are very much longer than they are broad. A great number of the meteors move round the sun in great groups, all flying with very nearly the same velocity and in the same direction. These great groups of closely associated meteors form great columns or streams, as it were, often several hundred thousand miles in diameter and many million miles in length. When the earth in its orbital motion passes through one of these great streams of meteors, grand meteoric showers are witnessed. At times, as in 1833 and 1866, the sky seems ablaze with meteors rushing through the heavens, thousands crossing the earth's atmosphere every second. In such cases the meteors seem to be moving so compactly that on the average only a few hundred yards separate one meteor from another; but this is most exceptional, for were the meteors separated from one another by an average distance of several miles, a brilliant shower would be visible, owing to the rapidity with which the earth and meteors pass each other. In general many miles separate the meteors from each other in an ordinary stream. The number of meteors in one of these large streams must be immense—it must be millions of millions of millions—yet their average size is so small (scarcely as large as a marble) that the entire mass, if collected, would probably not be sufficient to form a medium-sized minor planet. The great

Meteors.

Meteoric showers.

majority of such streams probably do not contain sufficient matter to form a planet even a couple of miles in diameter.

The last class of bodies moving round the sun in the solar system are the mysterious *Comets*, bodies about whose nature very little is really known. Some of them seem to be immense volumes of highly attenuated glowing gas, and others appear to be closely connected in some manner with the meteor streams which have been already mentioned. The dimensions of many of the comets are very great—many having volumes millions of times as great as that of the largest planet, and at times they are accompanied by bright tails many millions of miles in length. Yet their mass is very small, far smaller than that of the smallest of the eight principal planets; and even the largest comet probably has a far less mass than the average of the minor planets. The comets, like all the other members of the solar system, move in elliptical orbits, but in orbits of great eccentricity, so that their length is much greater than their breadth. The comets may be divided into two great classes—namely, those of short period, and those of long period. The former, some score of which are known, move round the sun in from three to thirty years; whilst the latter, numbering perhaps twice as many, require periods ranging between seventy and seven hundred years. There are a few whose period comes between the two. Some of these comets are bright enough to be conspicuous to the naked eye, but most are only to be seen with a telescope: these latter are known as *telescopic comets*.

Having thus described the general character of the members of the solar system, it will be well to give some more detailed account of the nature of the orbits in which they move, and of the manner in which astronomers are able to calculate the places of the planets, etc., in their orbits at any given time.

The size, form, and position of the orbit of a planet is fixed by five elements, as they are called, and when the arithmetical values of these are known it is possible to lay down a plan of the exact elliptical orbit in which the planet is moving. These elements are:—

I. The *Semi-axis Major*, or *Mean Distance*, commonly denoted by the letter a. It is equal to half the longer diameter of the ellipse forming the orbit of the planet—that is, to CA or CP in fig. 47. The mean distance of the earth is commonly taken as unity: thus the mean distance of Jupiter is said to be 5·2028, or is 5·2028 times that of the earth.

II. The *Eccentricity*, commonly denoted by the letter e. This is equal to the distance of the foci from the centre, the mean distance of the planet being taken for unity. It is SC on fig. 47.

These two elements determine the size and form of the orbit.

III. The *Longitude of Perihelion*, denoted by ω, or ϖ, or occasionally by π. This represents the longitude of the point on the orbit where the planet approaches closest to the sun; it is equal, therefore, to the longitude of the end of the major axis of the ellipse which is nearest the sun. This longitude, like all other longitudes, is measured from the point on the ecliptic where it cuts the celestial equator on passing from the southern to the northern hemisphere —a point called the *vernal* equinox. On the figure ♈ may be supposed to dènote the vernal equinox, when ♈N + NP = ω – the longitude of perihelion.

This element determines the position of the orbit with regard to the sun.

IV. The *Inclination*, commonly denoted by i. This represents the angle made by the plane of the orbit with the plane of the ecliptic. It is equal to the angle made by NP with NM on the figure.

V. The *Longitude of the Ascending Node*, commonly denoted by ☊. This represents the longitude of the point where the orbit cuts the ecliptic in passing from the south to the north, or to ♈N on the figure.

These two elements determine the position of the plane of the orbit in space.

These five elements give astronomers all the information they require about the form, size, and position of the orbit of a planet; but to these there is usually added a sixth, which enables them to ascertain at what part of its orbit the planet is at any moment. This additional element is—

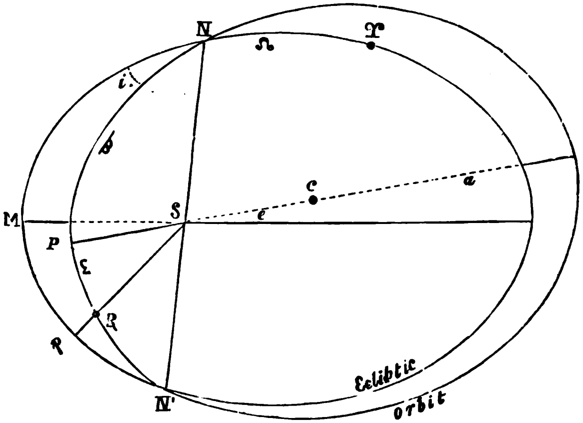


FIG. 47.

VI. The *Longitude of the Epoch*, commonly denoted by ϵ. This is the mean longitude of the planet at some given instant. If R be the position of the planet at this epoch, then ϵ = ♈N + NR on the figure. Usually it is the beginning of the year 1800, 1801, or 1850. In the case of comets this element is commonly replaced by the instant of passing its perihelion, and it is then commonly denoted by the letters *pp*.

The preceding six quantities constitute what astronomers call the elements of the orbit of a planet; but there are some other similar quantities to which astronomers often refer, which should be therefore described. They are the following:—

The *mean motion*, n.—It may be conveniently described as being equal to 2π, or 360° divided by the number of years which a planet takes to make a complete revolution. Suppose it be T years of 365¼ days each, then

$$n = \frac{2\pi}{T} = \frac{360^\circ}{T} = \frac{1296000''}{T}$$

Thus, in the case of Jupiter, the planet takes 11·862 years to make a complete revolution; hence

$$n = \frac{1296000''}{11\cdot862} = 109256'' = 30^\circ\cdot349.$$

The mean motions are usually given in seconds of arc, but are more convenient in degrees. Under these conditions the unit of time will be one year of 365¼ days. The mean motion and the mean distance of a planet are connected together by the law

$$n^2 = \frac{1}{a^3}, \quad \text{or} \quad n^2a^3 = 1;$$

only where this law is used, n must be expressed in circular measure by multiplying the number of degrees by the circular measure of one degree (= 0·0174533).

The *mean longitude*, l.—Suppose the planet to move in a circle round the sun at a uniform rate, so that it takes exactly the same time to make one complete revolution as the planet actually requires in its elliptic orbit. It must obviously move, therefore, in this circle at the same rate as its mean motion, and in any time t it will have moved through an angle equal to nt. Let t be reckoned from any instant assumed as an *epoch*, and by definition the mean longitude of the planet at that instant is denoted by ϵ. Then at the time t the mean longitude, l, of the planet will be equal to ϵ *plus* the angle nt it has moved through in the time t, or

$$l = nt + \epsilon.$$

In fig. 48 P R A represents the elliptical orbit of the planet, the sun being at S, and P being the perihelion. P R′ A is a circumscribing circle drawn round the ellipse from the same centre C, and P R″ is a smaller circle drawn round the sun as a centre. In the figure R is supposed to be the actual place of the planet in its elliptical orbit, and R″ the place of the fictitious planet which is supposed to move uniformly in a circle round the sun in the same time as the actual planet R. The two planets R and R″ are always supposed to reach perihelion together, and of course they then coincide in position. Thus R is termed the *true longitude*, v, of the planet, and R″ is termed the *mean longitude*, l. At P these two longitudes are the same, so that ω, the longitude of the perihelion, may be regarded either as its *true longitude* or as its *mean longitude*, as may be most convenient.

The *mean anomaly*.—This is equal to the mean longitude of the planet measured from the perihelion instead of from the vernal equinox. It is equal, therefore, to the mean longitude, l, less the longitude of the perihelion, ω, or

$$\text{Mean anomaly} = l - \omega = nt + \epsilon - \omega.$$

In the figure it is equal to the angle P S R″.

The *true anomaly*.—This is equal to the true longitude, v, less the longitude of the perihelion, ω, or

$$\text{True anomaly} = v - \omega.$$

In the figure the true anomaly is equal to the angle P S R.

These *anomalies*, therefore, only differ from the longitudes in being measured from the perihelion of the planet instead of from the vernal equinox.

The *eccentric anomaly* is equal to the angle P C R′, and is commonly denoted by u. Suppose a line drawn perpendicular to the major axis through the place of the planet R to the circumscribing circle, it will cut it at R′; then the angle at the centre of the ellipse between R′ and P is equal to the eccentric anomaly. It is obvious that when the planet is in perihelion the eccentric anomaly coincides with the true and mean anomalies.

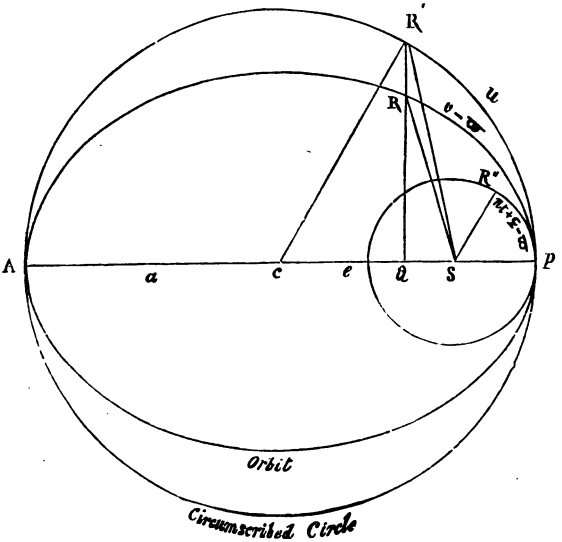


FIG. 48.

The *radius vector*. r.—This is the distance of the planet from the sun, measured on the plane of the orbit, and is equal to RS in the figure.

The *latitude*, λ, is equal to the angular distance PSR (fig. 47) of the planet above the ecliptic.

It remains to give the algebraical relation between these different quantities, so that one can be calculated from the other. These relations are—

$$\begin{aligned} nt + \epsilon - \omega &= u - e \sin u \\ \tan \frac{v - \omega}{2} &= \sqrt{\frac{1+e}{1-e}} \tan \frac{u}{2} \\ r &= a(1 - e \cos u) \\ &= \frac{a(1 - e^2)}{1 + e \cos (v - \omega)} \\ \sin \lambda &= \sin i \sin (v - \Omega) \end{aligned}$$

In general, however, astronomers want to calculate the longitude, radius vector and latitude of a planet at some given time; and for that reason they have transformed the above formulæ into others which give them the values of these quantities directly in terms of the mean longitude or the time, without its being necessary to proceed from one calculation to another. It is only possible, however, to give this second form to the formulæ by means of approximations in the form of long series of terms; but by taking enough of these terms into account, the result can be obtained as accurately as may be required. In the following expressions there have been omitted terms involving the third and higher powers of e:—

$$v = nt + \epsilon + 2e \sin (nt + \epsilon - \omega) + \tfrac{5}{4} e^2 \sin 2 (nt + \epsilon - \omega) + \dots.$$

$$r = a \left\{ \begin{array}{l} 1 + \frac{1}{2} e^2 - e \cos (nt + \epsilon - \omega) \\ - \frac{1}{2} e^2 \cos 2 (nt + \epsilon - \omega) + \dots\dots \end{array} \right\}$$

$$\lambda = i \times \left\{ \begin{array}{l} \sin (nt + \epsilon - \Omega) + e \sin (2\,nt + 2\epsilon - \omega - \Omega) \\ + e \sin (\Omega - \omega) + \dots \end{array} \right\}$$

In the preceding case the true longitude, v, is supposed to be measured on the plane of the orbit of the planet; when it is intended to find the place of the planet in the heavens, it is usual to suppose the longitudes to be measured on the ecliptic; in this case the following additional term must be added to the expression for v:—

$$- \tfrac{1}{4} \sin^2 i \sin 2(nt + \epsilon - \Omega).$$

It will be seen, therefore, that these formulæ enable us to calculate the longitude, radius vector and latitude of a planet, and therefore its place in the heavens, when we know the value of the six quantities or elements a (and therefore n), e, ω, i, Ω, and ϵ.

The values of these quantities are given in the table, where instead of n there has been given l, the motion in the mean longitude, a quantity which is larger by 50·23," the *precession*, as it is termed, or amount by which the vernal equinox moves backwards each year. Each of these elements or quantities is subject to slow variations, so that their values become slightly changed during the course of many years, but these alterations proceed so slowly that it takes centuries before any sensible change occurs.

TABLE OF THE ELEMENTS OF THE EIGHT PRINCIPAL PLANETS, ACCORDING TO LEVERRIER'S TABLES. Epoch 1850·00. (Mid-day, Jan. 1st, 1850, Paris Mean Time.)

Name.	Mean distance.	Motion of Mean Longitude.	Eccentricity.	Longitude of Perihelion.	Inclination.	Longitude of Node.	Longitude at Epoch.
	a	l	e	ω	i	☊	ϵ
Mercury . . .	0·3870987	4^{r} 54°·76071	0·205605	75° 7′ 14″	7° 0′ 8″	46° 33′ 9″	327° 15′ 20″
Venus . . .	0·7233322	1^{r} 225°·19212	0·006843	129° 26′ 35″	3° 23′ 35″	75° 19′ 44″	245° 33′ 17″
Earth . . .	1·0000000	1^{r} 0°·00769	0·016771	100° 21′ 21″	0° 0′ 0″	0° 0′ 0″	100° 46′ 43″
Mars . . .	1·523691	191°·41696	0·093261	333° 17′ 54″	1° 51′ 2″	48° 23′ 53″	83° 40′ 31″
Jupiter . . .	5·20280	30°·36301	0·048252	11° 54′ 58″	1° 18′ 41″	98° 56′ 17″	159° 56′ 13″
Saturn . . .	9·53885	12°·23508	0·055943	90° 6′ 56″	2° 29′ 40″	112° 20′ 53″	14° 50′ 28″
Uranus . . .	19·14169	4°·29864	0·046341	170° 50′ 7″	0° 46′ 20″	73° 13′ 54″	29° 17′ 51″
Neptune . . .	30·05437	2°·19886	0·008964	45° 59′ 43″	1° 47′ 2″	130° 6′ 25″	334° 33′ 29″

CHAPTER XII.

THE SUN.

Condition of the Sun—Spectrum Analysis—Spectra—Spectra of Compounds—Dark-line Spectra—Spectrum of the Sun—Elements present in the Sun—Solar Atmosphere—Red Prominences—Solar Granules—Nature of Solar Spots—Meteoric Origin of Solar Corona—Rotation of Sun—Diameter of Sun—Distance of Sun—Eclipses.

THE sun is the largest, most massive, and altogether the most important member of the solar system, serving as it were as the centre round which all the other members move. It consists of an enormous spherical body whose nature is quite unknown, surrounded by an intensely heated gaseous envelope; and all our knowledge of the constitution of the sun is confined to what we have learned about the nature of this envelope. What is beneath this envelope we do not know, though much speculation as to its probable nature has been indulged in by different astronomers—from Sir William Herschel, who at one time imagined that beneath the dazzling cloud-layer we see there might be another world, fairer and brighter, but analogous to our own, to Professor Young, who imagined that the sun might be a mere bubble and completely hollow in the interior. The intensely brilliant surface of the sun, which is all that we see, is merely the denser strata of its atmosphere rendered opaque by its great brightness: it is not improbable that the greater portion of the unknown interior of the sun may also be gaseous, and perhaps still hotter than the outer layer which we alone can see; but in the present condition of our knowledge all considerations of this nature must be considered merely speculative, without any real evidence to back them.

Condition of the sun.

Until recently it was supposed that we should never gain any knowledge of the materials which constitute the sun; though, reasoning from analogy, it was considered most probable that they would be analogous to those known to be the principal constituents of the earth. Twenty years ago a series of brilliant discoveries completely changed this, by revealing a method of analysing the light coming from any source, and by noting what rays were present and which were absent, learning what bodies had emitted these rays and through what bodies it had passed on its journey to the earth. These brilliant discoveries led to the foundation of a new branch of science, called *Spectrum Analysis*, which is founded partly on Optics and partly on Chemistry.

Spectrum analysis.

It had long been known that when a pencil of white light was passed through a prism it was spread out into a *spectrum*, as it was called, or a band of different coloured light—a band coloured like the rainbow, with red at one end, then orange, yellow, green, blue and violet. Every white-hot body was found to give the same rainbow-coloured band or the same continuous spectrum. Now, the main point in the discoveries which led to the foundation of this new

Spectra.

branch of science called spectrum analysis, was the discovery of the fact that when one of the metallic elements was heated to incandescence in a gaseous state, the light coming from it when passed through a prism no longer gave a continuous rainbow-coloured band, but a number of bright but different coloured lines of light. Thus when the vapour of metallic sodium, one of the chemical elements, was heated to incandescence, its spectrum was found to consist of two bright orange-yellow lines, very close together, instead of the long continuous rainbow-coloured band of light which was yielded by all hot solid bodies. Supposing, therefore, an astronomer proceeded to analyse the light coming from a yellow star, and instead of a spectrum consisting of a continuous rainbow-coloured band of light he found a spectrum consisting of two bright orange-yellow lines close together, he would know that the light from that star proceeded from incandescent sodium vapour. He would know, therefore, without ever having been there, or even having received any portion of the substance of that star, that it was composed of the chemical element called sodium.

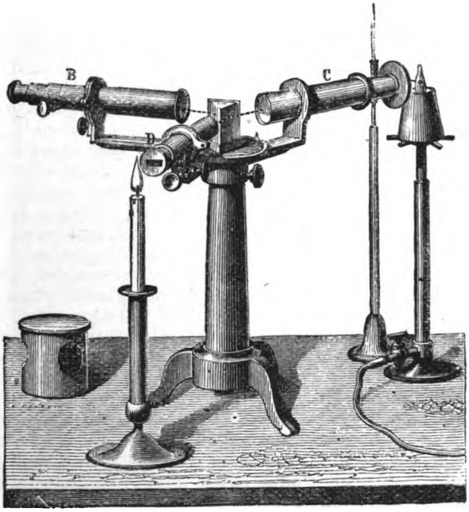


FIG. 49.—THE SPECTROSCOPE.

Spectra of compounds.

Further experiments led to still more important results: if it were only the elements which gave these characteristic spectra, and their compounds gave others, the number of these compounds is so immense that it would be impossible to identify them; but it was found that when any compound containing the element sodium was so heated as to yield an incandescent vapour, the light from this vapour yielded the two orange-yellow lines of sodium as distinctly as the vapour of the metal itself. Thus when common salt, which is a compound of sodium and chlorine, is heated sufficiently to yield an incandescent vapour, the light from this vapour gives the two orange-yellow lines characteristic of the presence of the element sodium. It was soon found that the other metallic elements gave similar characteristic spectra: thus the metal lithium gave one red and one orange line, potassium two in the red and one in the violet, thallium a vivid line in the green, calcium lines in the yellowish-green and orange. When two or more elements were present, it was found that each gave its own proper spectrum independent of the other; thus the light coming from the vapour yielded by an incandescent mixture of compounds of sodium and potassium would give a spectrum showing not only the two orange-yellow lines characteristic of sodium, but the red and the violet lines characteristic of potassium. It was soon found that it would be necessary to distinguish between different red or orange lines; but it was easy to do this by measuring their exact position in the spectrum, or say from some one point taken as a standard. Further experiment showed that many of the non-metallic elements also gave their characteristic spectra: thus incandescent hydrogen gave a spectrum of three conspicuous lines —one red, one greenish-blue, and one violet; oxygen gave a long group of lines principally in the blue and violet, and so with others.

The discoveries just mentioned, though very important, would not by themselves have thrown much light on the constitution of the sun or stars, for these bodies do not give spectra of bright lines, like those yielded by incandescent vapours. But these discoveries did not stop here; still further discoveries had been made. Thus it was found that if the light coming from a white-hot solid body, and yielding therefore a continuous rainbow-coloured spectrum, was made to pass through some sodium vapour, it no longer gave a simple continuous spectrum, as before, but the rainbow-coloured spectrum was now crossed in the orange-yellow by two black lines, in exactly the position where the hot sodium vapour would show its two orange-yellow lines. Other bodies were found to give the same results; thus hydrogen gas cut out three dark lines, one in the red, one in the greenish-blue, and one in the violet, in exactly the same place where lines of these colours would appear in its own spectrum. Thus, whenever the light coming from an incandescent solid body traverses a cooler gas, that gas cuts out from the continuous spectrum dark lines exactly corresponding in position with the spectrum it gives when it is itself incandescent. It was thus easy, from an examination of the dark lines crossing any continuous spectrum, to tell through what gaseous bodies the light had passed ere it reached the observer.

Dark line spectra.

This is of course a very slight outline of the foundation of the branch of science now known as spectrum analysis, but it will be sufficient to enable any one to understand the principles of this method, and the means by which astronomers have been able to determine the constitution of the gaseous envelope forming the visible portion of the sun.

The fundamental principles of this analysis may be summed up as follows :—

1. Every solid and liquid body when incandescent gives the same continuous rainbow-like spectrum.

2. Every gaseous body when incandescent gives a characteristic spectrum consisting of a number of bright-coloured lines.

3. Every gaseous body when traversed by a pencil of light absorbs the light-waves corresponding to its own characteristic spectrum, and yields a bright-coloured continuous spectrum crossed by dark lines in the same position as the bright lines in its own spectrum.

4. A gaseous body at very high temperature and of great density gives a continuous spectrum.

Spectrum of the sun.

Elements present in sun.

When the spectrum of the sun came to be examined by means of the spectroscope, or instrument used for obtaining the spectrum of a pencil of light, it was found to be a continuous rainbow-coloured spectrum crossed by an immense number of narrow black lines. The existence of these lines in the spectrum of the sun had long been known, as they had been discovered by Fraünhofer nearly fifty years before, and they were commonly known as Fraünhofer's lines. Then their origin and meaning were unknown: now these discoveries rendered it easy to interpret them. The white-hot lower-lying strata of the solar atmosphere gave a continuous spectrum, and the solar light in traversing the cooler upper-lying strata of the gaseous envelope, had cut out from it the light corresponding to their spectrum, so it emerged crossed by black lines corresponding in position to the spectrum of every constituent in the upper-lying layers of the solar atmosphere. It was only necessary, therefore, to identify these lines, to it once ascertain what were the constituents of the solar atmosphere. Three of the principal lines, in the red, greenish-yellow, and violet, were at once seen to correspond to the three lines in the spectrum of hydrogen ; a pair of very close lines in the orange-yellow agreed exactly with those of sodium; three close lines in the green with those of magnesium; others with those of iron, nickel, etc. It follows, therefore, that the constitution of the upper layers of the solar atmosphere is perfectly analogous to what might be expected from terrestrial analogies—in fact, similar to what would be the constitution of the gaseous envelope to the earth were it suddenly raised to the same temperature as the sun. So far, therefore, as our knowledge extends, the chemical constituents of the sun are in every way similar to those of the earth ; and extending the reasoning, we may consider it tolerably certain that the entire solar system is composed of compounds of the same elements as those found in the earth.

With the aid, therefore, of the additional information given us by the spectroscope, it is not very difficult to form a true idea of the probable condition of the surface of the sun, which is all that we can see. It is the upper-lying strata of a very dense atmosphere of very high temperature—an atmosphere agitated by storms, whirlwinds, and cyclones of all kinds, traversed by innumerable currents, and now and then broken by violent explosions. Above the brilliant surface which we see is a less dense and somewhat cooler upper

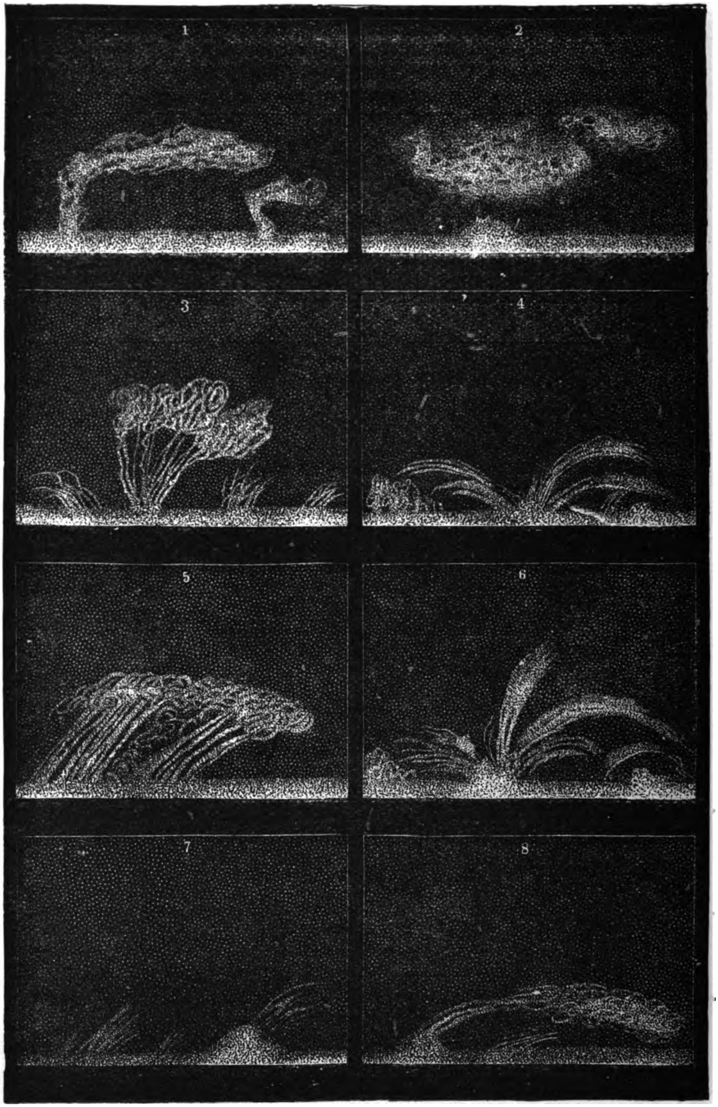


FIG. 50.—SOLAR PROMINENCES.

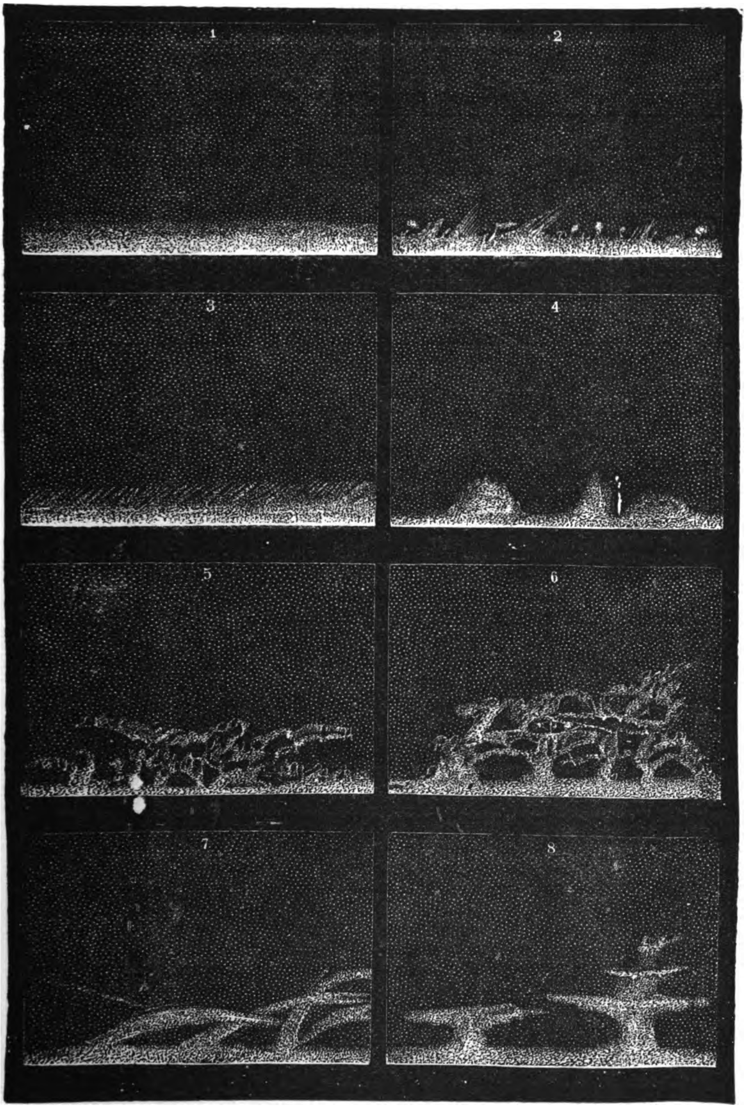


FIG 50.—SOLAR PROMINENCES.

stratum, which, though hot enough to shine quite brightly, is quite invisible in the presence of the brighter strata beneath it. Just before, or after a total solar eclipse the existence of this cooler stratum has been revealed by the spectroscope. We know that if we pass a beam of light through a mass of hot sodium vapour we obtain a continuous spectrum crossed in the orange-yellow by the two dark lines indicating sodium; but now if we cut off the beam of light, then the sodium vapour gives us its two bright orange-yellow lines. It is the same with the sun: the existence of this cooler outer envelope is indicated by the numerous dark lines shown by the solar spectrum, but cut off the light coming from the lower lying dense strata of the solar atmosphere, so as to get rid of the continuous spectrum, and then this upper-lying layer gives its own bright-line spectrum. Hence, as just before the beginning of totality in a solar eclipse the moon cuts off all the light coming from the lower-lying strata, and for a second or two lets pass only the light from the extreme edge of the sun, or the light from the uppermost strata, so during this instant the continuous spectrum, with all its dark lines, ought to be replaced by a spectrum of many brilliant-coloured lines. This was first seen by Professor Young, and since then has been witnessed by other astronomers. The existence of this absorbing medium explains why the portion of the sun near the edge of the disc, or limb as it is called, is not so bright as the central portion; for the light from these portions having to pass through a greater thickness of atmosphere, they lose a greater portion of their light by absorption.

Solar atmosphere.

Reference has already been made to the curious *red prominences* or *flames*, seen round the sun during solar eclipses. The spectroscope soon showed these to be no other than immense masses of incandescent hydrogen gas. By means of the spectroscope these can now be studied at all times when the sun is visible, it no longer being necessary to wait for solar eclipses. It is found that all round the sun there is an envelope of incandescent hydrogen gas; but that here and there it projects outwards in the enormous protuberances which have been seen in solar eclipses. These prominences take all sorts of curious forms and shapes, and at times vary from hour to hour in shape and dimension. At times they have been seen to rise quickly in enormous cloud-like masses, as if hurled upwards by some tremendous explosion below, and sway and bend into a thousand fantastic shapes whilst you watch them. Occasionally these prominences show the lines of sodium, and of some unknown element, showing that they consist at times of the vapours of these bodies as well as of merely hydrogen.

Red prominences.

When the solar surface is closely examined, it is found to be curiously mottled over as if with pores. With more powerful telescopes this is seen to be due to the surface being composed of innumerable brighter granules on a darker ground. These granules have been likened to *rice grains* by some astronomers, and to *willow leaves* by others; they are most likely the summits of the rounded cloud-like masses which probably constitute the visible surface of the sun. In places, but especially in the vicinity of spots, are to be found the bright patches

Solar granules.

called *faculæ*, which seem to be masses of denser or brighter vapour that have been hurled to the surface by the same violent internal agitations or storms which create the spots themselves. At other times they would appear to be the bases of the solar prominences or red flames.

Nature of solar spots.

The *dark spots* themselves would seem to be due to either uprushes from below or to downpours from above, or perhaps at times to one and at times to the other; in both cases there would result a break in the bright light yielding strata by masses of cooler vapour. They would thus correspond to whirlpools or cyclones in the solar atmosphere. Imagine some terrible disturbance beneath the surface to hurl dense masses of gas to the surface, breaking through the visible bright layer; as the dense masses of gas rose the pressure would diminish with tremendous rapidity, and the gases would expand enormously, causing a great reduction in the temperature of the gas, and so rendering it much cooler. It would thus evolve less light and appear as a dark spot upon the sun. The whole appearance of the solar spots is in thorough accord with this explanation of their probable origin.

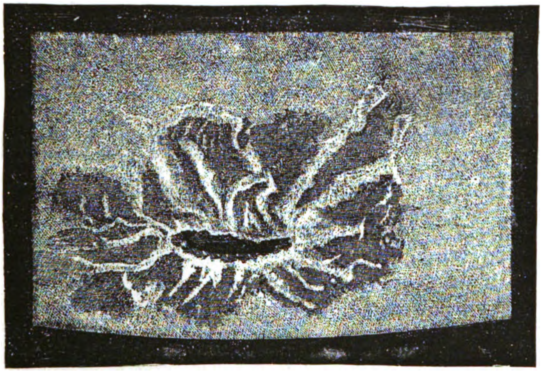


FIG. 51 —SPOT ON THE SUN'S DISC.

It was early discovered that the spots seemed far more numerous near the equatorial region of the sun than elsewhere, rarely appearing in greater heliographical latitudes than 35°, though occasionally spots have been seen at a greater distance from the equator. In dimensions they are, as a rule, not greater than 10″ or 15″, but at times have been known to exceed 50″ in diameter; whilst groups of spots with more or less common penumbræ have exceeded even this in dimensions. When it is remembered that 1″ on the solar surface corresponds to over 400 miles, the immense dimension of these spots may be understood. It has already been mentioned that they undergo well-marked periodical variation in their frequency—at times scarcely any being visible, and at others there being hardly a day when four or five cannot be seen. Further investigation seems to show that these periodical variations have a mean period of 11·11 years, but at times the epochs of maximum are separated by longer or shorter intervals than this,—two maxima being at times separated by only eight years, and at others by as much as thirteen years. Some astronomers have fancied that they have traced a correspondence between the variation in the number of sun-spots and the terrestrial magnetic variation, with the number of auroræ, terrestrial cyclones, famines, and many other things; but all these deductions rest on very imperfect data. The mere coincidence in mean period so strongly insisted on by some observers proves nothing, because some such coincidence must be found for every period if only diligently searched for. Other astronomers have ascribed the formation of the spots to the action of the planets, and especially of Jupiter; because that giant planet moves round the sun with a like period of some eleven odd years. Beyond this slight coincidence little else has been found to show any connection between the two.

Reference has already been made to the bright *corona* seen to surround the sun during solar eclipses. By the aid of the spectroscope this has been shown to shine partly from reflected solar light and partly from inherent light of its own; so that it probably consists partly of solid particles and partly of incandescent gas.

Meteoric origin of solar corona.

It is probable, therefore, that the corona consists of an immense number of minute meteoric masses, each surrounded by its own gaseous envelope, and rapidly revolving in its orbit round the sun. The greater masses of these meteors probably revolve in orbits which lie far within the orbit of Mercury; but many must move in orbits which extend far into the solar system. Observation has shown us that there are an immense number of streams of meteors moving in all directions round the sun, and in orbits of all shapes, but in general resembling in form the orbits of the periodical comets, and often closely associated with them. The earth is known to cross the path of several hundred of these meteor streams, and probably does cross the path of several thousand; so that the number in the solar system must be counted by hundreds of millions at least. Each of these streams must pass close to the sun, so that the entire region near the sun must be crowded with innumerable meteor streams. The solar corona, which is seen during solar eclipses, is probably due to these innumerable meteors swiftly flying round the sun, and radiating away in all directions into space,—the light of the *corona* being due partly to those of the meteors which have passed close enough to the sun to have been rendered white-hot, partly to their gaseous envelopes also rendered incandescent, and partly to the solar light reflected by them.

From careful observation of the spots on the sun it has been ascertained that the sun rotates on an axis inclined at an angle of 7° 17′ to the perpendicular to the ecliptic, once in 24 d. 23 h. 18·4 m. (Carrington), though according to Schwabe these quantities ought to be 25 d. 5 h. and 7° 17·7′, and according to Spörer 25 d. 5 h. 37 m. and 6° 58′. The longitude of

Rotation of sun.

the ascending node of the sun's equator is 73° 50′ according to Carrington, and 74° 48′ according to Spörer. Some uncertainty attaches to these determinations, because the solar spots seem usually to possess proper motion of their own, the spots nearer the equator moving more quickly than those farther away.

In form the sun seems perfectly spherical, the most careful micrometrical measures having failed to show any sign of any polar compression, though from its slow rotation on its axis some such compression would not have been abnormal.

Diameter of sun.

Seen from the earth, the mean diameter of the sun is 32′ 3·6″, but as the distance of the earth varies, so does the apparent diameter of the sun—it being at its smallest, or only equal to 31′ 31·8″, on July 1st, when the earth is at its greatest distance; and at its largest, when it is equal to 32′ 36·4″, on December 31st, when the earth is at its least distance from the sun. It thus varies by 1′ 4·6″. The actual diameter of the sun is easily calculated when once the distance of the sun is known. If the solar parallax be taken at 8·80″, then the actual mean distance of the sun is 92,880,000 miles, or nearly ninety-three millions of miles; and from the apparent diameter of the sun, or 32′ 3·6″, the real diameter must be 866,000 miles.

Distance of sun.

The methods for determining the real distance of the sun by determining the value of the solar parallax, or apparent displacement in the position of the sun as seen from different places on the earth, has already been described. It remains only to mention the values which have of late been determined; for unfortunately at present the exact value of this most important astronomical constant is not known with certainty. From the motion of the planets, M. Leverrier deduced a value which, after applying certain necessary small corrections, becomes equal to 8·84″. From a re-discussion of the celebrated transit of Venus of the last century, Mr. Stone found the value 8·91″. From the last transit of Venus, in 1874, Col. Tupman has found the value 8·84″; but unfortunately the observations made during this last transit have turned out to be so uncertain that this result is of very little weight. From an expedition to observe the parallax of Mars during the very favourable opposition in 1877, Mr Gill has obtained the value 8·78″. From the value of the parallactic inequality in the motion of the moon, Messrs. Neison and Campbell have obtained the value 8·78″ or 8·84″, but further research is required to determine which value is correct. From the photographs taken by the American observers during the transit of Venus, Mr. Todd obtains the value 8·88″. From the French photographs taken during the same transit, Mr. Stone has derived the value 8·88″. It will thus be seen that there is a very considerable uncertainty, the results ranging between 8·78″ and 8·91″; and as a change of 0·01″ in the solar parallax corresponds to a change of 104,000 miles in the distance of the sun, it will be seen that this uncertainty is not satisfactory. It is probable, however, that the true value is very close to 8·80″. If the solar parallax be taken as 8·80″, the distance of the sun from the earth will be 92,880,000 miles; and it is probable that this is within half a million miles of the truth.

The principal phenomena presented during solar eclipses have been already described, and at present they present few features of interest except in regard to what further information may be learnt about the solar corona ; and it is doubtful whether this appendage to the sun should not be properly dealt with in the section of Intra-Mercurial Planets, under which head of course comes the search for these bodies, which can only be satisfactorily pursued during the course of a total solar eclipse. During every year there are at least two eclipses of the sun, and there may be as many as five in the one year; but the number visible from any one place on the earth is much smaller, and many years may elapse before a second total eclipse is visible at any given place. This is from the fact that a solar eclipse is never total over an entire hemisphere of the earth, but as a rule is only total over a narrow belt about one hundred miles in width, although it may be visible as a partial eclipse over a far wider area. It will not be for very many years that another total solar eclipse will be visible in England, or even an annular eclipse.

Eclipses.

CHAPTER XIII.

INTRA-MERCURIAL PLANETS.

Suspected Existence of Intra-Mercurial Planets—Their probable Nature—Supposed Observations of Intra-Mercurial Planets—Certainly not such Planets—Vulcan—Probable Nature—Zone of Intra-Mercurial Planets—Supposed Observations of these Planets.

WHEN Leverrier, the famous French astronomer, had completed the first portion of his investigation of the motion of the planets, he found that he could not account for the observed motion of the perihelion of the planet Mercury unless he assumed the existence within its orbit of some unknown body or bodies having a mass amounting in the aggregate to nearly that of Mercury itself. Leverrier considered, therefore, that it was certain that there existed within the orbit of Mercury yet another planet or planets, or else a ring of small minor planets similar in size and character to the great belt of such bodies which exists between Jupiter and Mars.

Suspected existence of intra-Mercurial planets.

Which of these is the more probable? The question can now be answered with much greater certainty than it could be a quarter of a century ago, when it was first propounded.

If there be such a planet or planets, there are three ways in which it might be detected. Firstly, in the same way as the planet Mercury itself can be found—by watching the neighbourhood of the sun; when, if the planet were anything like half the size of Mercury, it could be detected, as it would shine with much greater intrinsic brightness, owing to its nearer proximity to the sun. Secondly, even if too small to be thus seen, during a solar eclipse the solar glare disappears, and stars of even the second magnitude can be seen quite close to the sun, whilst the planet Mercury shines forth most conspicuously even to the

Their probable nature.

naked eye. Any intra-Mercurial planet large enough to shine like a first or even second magnitude star might be at once detected in this manner. Thirdly, it might be seen when in transit across the solar disc, and as the planet would be much closer to the sun than Mercury, it would be far oftener observed in transit—probably at least once in every other year. Owing to the irradiation or the encroachment of the bright light of the sun upon the dark body of the planet, when seen in transit across the sun a planet is diminished in apparent diameter by over 2″ of arc, so that it would look smaller than its real dimensions, and so much less conspicuous than might otherwise be anticipated. If, however, the planet were 2000 miles in diameter when it crossed the solar disc, its real diameter would be about 5″, so that it would appear like a small circular black spot some 3″ in diameter. It is not likely that such a spot could repeatedly cross the sun without being detected in transit.

If there were one such planet, it could not have a mass even half as great as that required by Leverrier's theory unless its diameter was equal to 2500 miles. Such a body would shine like a star of the first magnitude, and when it crossed the solar disc would appear like a spot over 4″ in diameter, whilst it would be visible at elongation as a beautiful exceedingly brilliant crescent some 7″ in greatest diameter. A planet of this kind could not have escaped detection, and a very careful search has been made for it without result.

Supposed observations of intra-Mercurial planets.

Here, however, it is necessary to notice some remarkable observations which have been made, and which have led to the frequent suspicion of the existence of such an intra-Mercurial planet. These observations consist of a number of instances, more or less well authenticated, where small dark circular spots have been seen to cross the whole or part of the solar disc, as if they were intra-Mercurial planets in transit.

On November 19th, 1762, Lichtenberg, a young German astronomer, observed a large round spot upon the sun, and noticed its egress after having traversed a chord of some 70°. On March 29th, 1800, and February 7th and October 10th, 1802, Fritsch, another German astronomer, observed spots on the solar surface which moved in so exceptional a manner that it was supposed that they might be planets *in transitu.* On January 6th, 1818, a Mr. Capel Lofft and two others saw a small black spot move regularly across the sun. it disappearing shortly before sunrise. On July 12th, 1837, De Vico at Rome made a similar observation; and on October 2nd, 1839, Decuppio at the same observatory yet another. Similar observations were made by Scott and Wray in the summer of 1847; by Sidebotham and Lowe on March 12th, 1849; by Ohrt on September 12th, 1857; by Russell and others on January 29th, 1860; and by Lummis on March 20th, 1862.

All these observations seem to have been instances of round dark spots of nearly the apparent size of Mercury when in transit, or from 8″ to 15″ in diameter, so that they would indicate the existence of a planet from 4000 to 7000 miles in diameter. Such a planet would shine nearly as bright as Venus, and would be so distinct, especially during solar eclipses, that had it existed it must long ere this have been detected. Either, then, these observers very much exaggerated the dimensions of the object they saw, or it was not a planet in transit. If they were not deceived in thinking the bodies actually moved as they described them, then their observations would seem most perplexing. They might be comets, they might be gigantic meteors moving quite close to the earth, and in the same direction, with nearly the same velocity; but it is certain that they were not intramercurial planets.

Certainly not such planets.

There is, however, one of these observations which stands out from the rest. Shortly after Leverrier had announced his theoretical conclusions, a Dr. Lescarbault, a French amateur observer, sent him an account of an observation of the transit across the sun of a body which he regarded as that of an intra-Mercurial planet. On March 26th, 1859, Lescarbault saw a small circular black spot, about 3″ in diameter, cross part of the solar disc, and egress from the sun at a determined time. Leverrier made an elaborate inquiry into this observation, and soon satisfied himself that it was genuine. Employing the data furnished by the Doctor's observations, he deduced the distance and elements of the orbit of the supposed new planet, which was named *Vulcan*. Arrangements were made to watch for it at the epochs of its next transits. Yet, though repeated searches have been made for it, this planet Vulcan has never been seen again. From Lescarbault's description, the real diameter of this planet must be about 1800 miles, so that it would under favourable circumstances shine like a star of the first magnitude; yet it has never been seen near the sun at the time of solar eclipses, though often looked for. It would seem, therefore, that either Lescarbault over-estimated the size of the body, or else it falls into the same category as the preceding observations.

Vulcan.

It may be regarded as certain that if such intra-Mercurial planets really exist, their actual diameter does not exceed 1500 miles, and is probably not greater than 1000 miles. Such bodies would, under favourable conditions, shine like stars of the second or third magnitude, and show bright little crescents about 3″ to 4″ in diameter, but when in transit across the sun they would be diminished by irradiation to tiny circular black points scarcely 1″ in diameter. They would thus be very difficult to detect *in transitu*, and would not be easy to discover except with a telescope even at the time of solar eclipses. Were their diameter less than 1000 miles, they would scarcely be visible in crossing the solar disc, and could only be detected with considerable trouble even during a total eclipse of the sun.

Probable nature.

If, then, there existed a ring of minor planets, in size and number resembling the great group which move round the sun in orbits lying between those of Mars and Jupiter, they would be too small to be detected when crossing the sun, and would be exceedingly hard to see even during solar eclipses, for the diameter of the largest of the minor planets does not probably exceed 500 miles, and most are much smaller. Leverrier's theoretical investigations would lead us to believe in the existence of such a belt, and if subsequent investigators confirm them,

Zone of intra-Mercurial minor planets.

this belief will be much strengthened. It is true that a portion of the mass may exist in the form of the numerous meteor streams known to move round the sun, and which for a considerable portion of their paths are within the orbit of the planet Mercury; but these cannot explain more than a small portion of the required mass, or they would disturb Venus as well as Mercury.

Supposed observations of these planets.

But of late observations have been made which, whilst tending to confirm the supposed existence of a belt of minor planets within the orbit of Mercury, would also tend to show that some members of this group are much larger than the corresponding *ultra-Martial* system. During the solar eclipse of 1878, Professor Watson, an American astronomer of considerable eminence, observed one or two brilliant star-like bodies near the sun, in places where no such stars are known to be. These bodies shone even in the glare as stars of the fourth magnitude, and appeared with rounded discs 3″ or 4″ in diameter. Their real dimensions would thus appear to be from 800 to 1000 miles in diameter, or practically twice the size of the largest known minor planet. Some uncertainty still attaches to these observations, for at some little distance away there were a pair of stars which might correspond to the objects seen by Professor Watson, if he had made some error in marking the position of the bodies seen by him, and had somewhat over-estimated their brightness.

Further opportunities must be awaited before this very interesting question can be settled.

CHAPTER XIV.

MERCURY AND VENUS.

Mercury—Size and Appearance—Transits of Mercury—Venus—Physical Condition—Markings—Transits.

MERCURY.—This planet, from its proximity to the sun, is only occasionally well placed for observation, so that the amount of information possessed by astronomers as to its appearance and physical condition is very meagre. It is a spherical planet 3000 miles in diameter, with a mass of about 1 ÷ 5,000,000 of that of the sun, so that in density it is about equal to the earth. It is surrounded by an atmosphere of considerable density and thickness, so that it is probable that astronomers never see the real surface of the planet, but only the upper cloud-layers. When carefully scrutinised with large telescopes, Mercury appears like a golden white disc, which takes all the phases of the moon, varying in appearance from a minute little disc 5″ in diameter, to a bright quadrant 7·5″ in diameter when near its greatest elongation from the sun, and thence to a brilliant little crescent nearly 12″ in diameter when approaching inferior conjunction. The real diameter of Mercury, when seen at the same distance as the sun from the earth, appears to

Size and appearance.

be 6·76″, but when seen in a telescope it looks larger owing to the fringe of fictitious light due to irradiation. At times astronomers have observed faint grey spots and streaks on the planet, and from these observations it has been supposed that Mercury rotates on an axis inclined 70° to its orbit once in 24 h. 0 m. 53 s., but very great uncertainty attaches to these results. One of the most interesting phenomena presented by Mercury is its transit across the solar disc. These are not uncommon. The next occurrences are May 9th, 1891, and November 10th, 1894, both of which will be visible in England; the last one was November 7th, 1881, but was not visible in England. The planet appears like a round black spot, about 10″ in diameter, and surrounded by a faint ring of light, which at ingress and egress is visible as a bright ring of light surrounding the portion off the sun. Some astronomers have during the transit seen one or more bright spots near the centre of the planet, probably due to some purely optical effects of contrast.

Transits of Mercury.

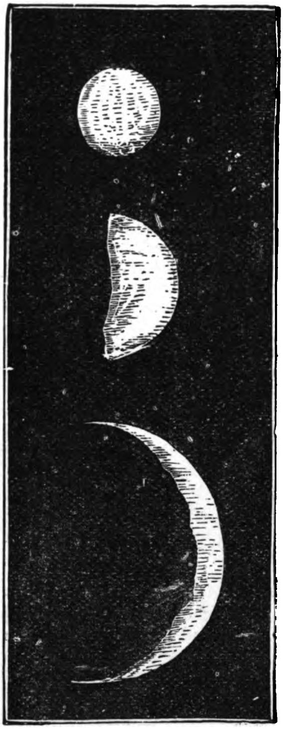


FIG. 52.—MERCURY.

VENUS.—This beautiful planet is at times one of the finest objects in the heavens, shining so brilliantly as to dwarf even the great lustre of the giant Jupiter, and casting a distinct shadow on a moonless night. It is readily visible at such times in broad daylight, appearing as a tiny white speck on the deep blue noonday sky.

Venus, of all the planets in the solar system, is the one which most nearly approaches the earth in character, there being indeed but one feature of any importance wherein Venus and the earth differ, and that is in the possession of a satellite: Venus has no moon. In all other respects the two planets much resemble each other. The diameter of Venus is 7900 miles, which is almost exactly that of the earth; its mass is 1 ÷ 400,000, which is about five-sixths of that of the earth, so that it has a slightly less mean density. From a number of observations of grey spots on the planet it has been calculated that Venus rotates on an axis inclined at 41° to its orbit once in 23 h. 21 m. 22 s., but, as in the case of Mercury, this result is very uncertain. In the telescope Venus varies in appearance from a tiny yellowish disc only 10″ in diameter, when beyond the sun in superior conjunction,

Physical condition.

to a brilliant silvery-white crescent 67″ in diameter when between the earth and sun in inferior conjunction; it appearing like a yellowish-white brilliant quadrant 20″ in diameter when near its greatest elongation. The true value of the diameter of Venus, when at the same distance as the sun from the earth, is 17·55″, but in the telescope, from its great brightness, it is so enlarged by irradiation as to appear from 1½″ to 2″ greater.

Venus is surrounded by a considerable atmosphere which manifests its appearance during the transits of the planet across the sun by surrounding its disc with a narrow ring of brilliant silvery light, this ring being most noticeable at ingress and egress; but whenever the planet approaches very closely to the sun during inferior conjunction, the atmosphere manifests its presence by refracting the solar rays until the planet appears surrounded by a complete circle of light. From the observations made under these conditions by Madler and Lyman, it would appear that the amount of this refraction shows the density of the atmosphere of Venus to be nearly twice the density of the terrestrial atmosphere. Probably, therefore, what is seen when Venus is examined in a telescope is merely the upper cloud-bearing strata of its atmosphere. This view is in accord with the results of observation, for it is rarely that anything can be seen on the disc of Venus but a uniform yellowish-white surface. Occasionally very faint cloud-like grey markings have been detected, but they are very faint and their very existence uncertain. Traces of the effect of this atmosphere can be seen in the manner in which the border between the illuminated and unilluminated portions of the planet fade one into another (fig. 53), and also in the manner in which the cusps of the planet are prolonged (fig. 54). From observations with the spectroscope, Tacchini considers that this atmosphere contains traces of aqueous vapour.

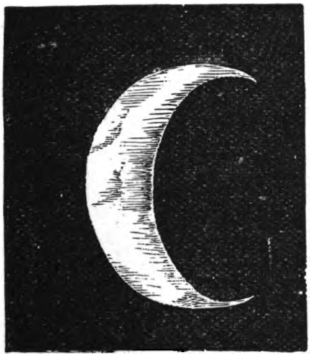


FIG. 53.

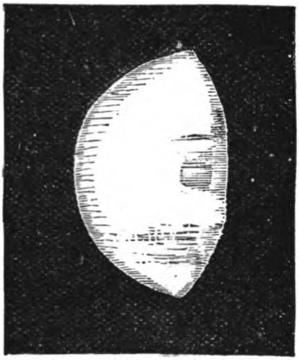


FIG. 54.

Markings.

Judging from analogy, it is probable that the constitution of Venus is very similar to that of the earth, only its greater proximity to the sun and denser atmosphere combine to keep its skies perpetually covered with cloud, and so prevent our ever obtaining a view of the real surface of the planet, unless the faint grey spots be glimpses as if through a mist at the surface beneath. Were it not for this, Venus would be of all the planets the one best situated for study by us.

The transits of Venus across the sun are very rare phenomena, only two occurring every 130 years. The first transit was observed by the Rev. Jeremiah Horrocks, on 24th Nov. 1639. When seen in transit, Venus appears like a very considerable dark round spot, some 64″ in diameter, and surrounded by a ring of light due to the presence of its atmosphere. Several observers have noted a bright spot on its centre, due probably to the same optical cause as the spot or spots seen on Mercury under similar conditions.

Transits.

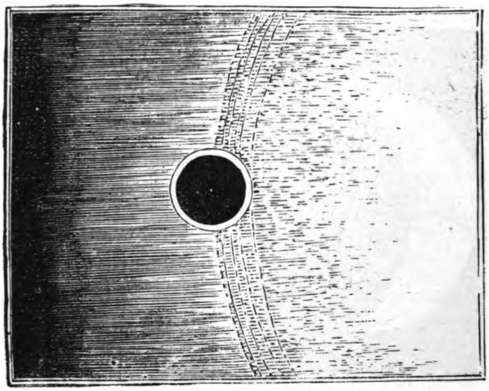


FIG. 55.

Years ago a considerable number of observers saw at different times an object which they believed to be a satellite to Venus, some of these observers being astronomers of considerable experience. Yet, though often searched for during the present century, this pseudo-satellite has never been seen. That Venus has no such satellite is now absolutely certain; what body was it which was seen by the early observers? Was it merely an optical illusion, due to some improper reflection of light from the eyepiece, or perhaps from the side of the telescope—a *ghost*, as it is called? The latter is not an uncommon phenomenon; but some of the earlier observers seem to have taken great precautions to make sure it was not due to this cause. If not, what was the body?—one of the intra-Mercurial planets? Not impossibly, it may have been one of these: we cannot tell.

CHAPTER XV.

THE EARTH AND THE MOON.

The Earth—Astronomical Constants—The Moon—Lunar Observations—Dimensions—Revolution—Physical Condition—Has the Moon an Atmosphere?—Plains, Mountains, and Craters—Conclusions.

THE EARTH.—This member of the solar system scarcely comes within our scope, except in so far as concerns certain astronomical constants; its size, history, and physical condition coming within the domain of geography and geology rather than astronomy. There are certain astronomical constants, however, which must be noted.

Astronomical constants.

The earth is an oblate spheroid, with an equatorial diameter of 7926·6 miles, and a polar diameter of 7899·6 miles, corresponding to an ellipticity of 1 ÷ 292·96. There is, indeed, some reason for supposing the earth to be ellipsoidal in form, but our knowledge on this point is at present most uncertain. The mass of the earth is about 1 ÷ 327·000 of that of the sun, and the mean density about 5½ times the density of water. The earth rotates on its axis once in twenty-four hours, and the axis is inclined to the terrestrial orbit by an angle of 66½°; the obliquity of the ecliptic, or angle between the ecliptic and equator, being on January 1st, 1850, equal to 23° 27′ 31·83″ (Leverrier). It is slowly changing—decreasing every year by 0·47″. This decrease will not be perpetual, however, as the obliquity of the ecliptic only varies between the limits 21° 58′ 36″ and 24° 35′ 58″. The equinox, or point where the ecliptic and equator cut one another, is slowly receding—the amount of this recession, or the precession of the equinoxes, as it is called, being 50·236″ per annum in the year 1850, it very slightly altering in the course of centuries. From this cause the apparent longitude of all the stars and other heavenly bodies increases by this amount every year. The best values for the two other similar astronomical constants are 9·236″ for the *Nutation*, and 20·445″ for *Aberration*.

THE MOON.—The moon, from its close proximity to the earth, affords an opportunity for studying the physical condition of another member of the solar system under exceptionally favourable conditions. In the case of the moon, instead of being restricted to observing the broad features of their physical condition, which only afford us material for guessing at some of the more prominent features of their past history and future career, we can study the minuter details, and so learn much which gives a clue to the exact causes which have produced the effects we see. The observations of the moon possess, therefore, an interest and importance of their own, which lend an exceptional charm to the study of selenography. Nor is this charm decreased by the conviction, soon acquired from the study of the lunar surface, that the forces which have brought the moon to its present condition are the same forces which have moulded the earth, so that the past history of our earth is written in the clearest characters upon the surface of the moon. This lends a great fascination to the study, for it creates for it an interest and importance which is possessed by the observation of no other member of the solar system. Much of the past history and future career of the earth might undoubtedly be learnt from observation of the physical condition of Venus, could we only see the surface; but we are restricted to seeing only the clouds in its skies, and these afford us no information as to the history of the planet beneath.

The moon moves round the earth in an elliptical orbit, whose greatest semi-diameter is 252,970 miles, and whose least semi-diameter is 221,610 miles, its mean distance from the earth being 238,840 miles. The constant or mean value of the equatorial horizontal parallax of the moon is therefore 57′ 2·325″. The eccentricity of this elliptical orbit is continually varying between small limits, owing to the disturbing action of the attraction of the sun upon the moon in its motion round the earth ; but it continually fluctuates on either side of the mean value, 0·054908. The position of the lunar perigee, or point of the lunar orbit which is nearest the earth, is also continually moving, and makes a complete circuit of the orbit in 8·85 years ; for convenience, the mean position of the lunar perigee may be regarded as moving round the orbit with a uniform motion at the rate of 40° 40′ 31″ per year, and the actual position as vibrating to a small extent on either side of this mean position. The inclination of the lunar orbit to the ecliptic is equal to 5° 8′ 40″, but is subject to slight variation on either side of this value. The nodes of the lunar orbit move round the moon in the same manner as the position of the lunar perigee, but in the opposite direction; for whilst the longitude of the perigee is continually increasing, the longitude of the nodes is continually decreasing, this decrease being at the rate of 19° 21′ 18″ per annum, taking 18·60 years for a complete revolution.

The mean sidereal revolution of the moon, or the time of one complete revolution round the earth, is 27 days 7 h. 43 m. 11·54 s., but its mean synodical revolution, or the mean duration of a month, is 29 days 12 h. 44 m. 2·68 s. The mean diameter of the moon is 31′ 8·00″, it ranging according to the varying distance of the moon from the earth between the two extremes of 33′ 33″ and 29′ 24″. Combining this with the known distance of the moon, it results that the actual diameter is 2163 miles. The surface of the moon is therefore only 1 ÷ 13·43 times that of the earth, and its volume only 1 ÷ 49·20. The mass of the moon is only 1 ÷ 81·40, so that its mean density is only 0·6042 of that of the earth, or equivalent to about 3½ times that of water. Owing to this smaller mass and density, the action of gravity at the lunar surface is much smaller than on the terrestrial surface, being only equal to 0·1649 of the earth's, or rather less than one-sixth.

As the moon takes the same time to rotate on its axis as it does to make a complete revolution in its mean orbit, it would always turn exactly the same face to the earth were both its axial rotation and orbital revolution made throughout with uniform velocity, and were the lunar orbit and equator in the same plane as the terrestrial orbit. But not only are the lunar equator and orbit inclined at small angles to the ecliptic or terrestrial orbit, but whereas the moon rotates on its axis at an almost absolutely uniform rate, it moves in its orbit with very different velocities in different parts and at different times. Accordingly the moon does not always present exactly the same face to the earth, so that instead of the apparent centre of the lunar disc being always at the same point on the lunar surface, it is ever swaying from one side to another of its mean place—the place it would invariably occupy were it not for the small angles made by the lunar orbit and equator with the ecliptic, and for the variable orbital velocity of the moon. This apparent swaying to and fro of the apparent centre of the lunar disc is called the *optical libration* of the moon, as it does not arise from any actual irregularity in the rotation of the moon upon its axis, but is an optical effect due to the inequalities in the motion of the moon in its orbit and to the inclination of its equator and orbit to the ecliptic.

The librations are measured in selenographical longitude and latitude, which are measured in exactly the same manner as terrestrial longitude and latitude—namely, longitudes are reckoned east and west from the lunar first meridian, and latitudes north and south from the lunar equator. West longitude and north latitude are usually called positive, and denominated by the sign +, and east longitude and south latitude are denominated by the sign —, and called negative. The first meridian is the great circle which passes through both poles of the moon, cutting the equator at right angles in the point which is at the mean centre of the lunar disc when there is no libration. This *libration* of the moon may amount to as much as 7° 54′ in selenographical longitude and 6° 51′ in selenographical latitude, the greatest displacement of the apparent centre of the moon being at times as much as 10° 25′.

From the effect of this libration we see at different times more than half of the entire lunar surface, as, owing to the effect of the libration, different portions of the edges of the further hemisphere are at different times brought into view. It has been calculated that in this manner we see at different times as much as 0·59 of the entire surface of the moon, only 0·41 part remaining invisible.

There is also a similar libration called the diurnal libration, and equal to the parallax of the moon, it being due to the same cause—namely, that we observe the moon from the surface of the earth and not from its centre, and so seeing the moon from a different position, see it apparently in a somewhat different place.

When the moon is at its mean distance, one degree of selenographical longitude and latitude at the centre of the lunar disc subtends an angle of 16·6″ and measures 18·87 miles, so that under these conditions one second of arc is equal to 1·14 mile, and extends over 3′ 37″ of selenographical arc. As one second of arc is usually the smallest object which can be readily seen in an ordinary telescope, it follows that the smallest features that can easily be seen on the moon must be about one mile in diameter. This may be compared with the 100 miles which is the diameter of the smallest spot to be seen on Venus, or 180 miles on Mars, the two most favourably placed planets.

When the lunar surface comes to be attentively studied with the aid of a good telescope, it will gradually become manifest that, though no copy of the earth, its structure is in every manner of identical nature; everywhere will be found analogous manifestation of similar forces, so that the great formations of the moon are merely other examples and other forms of the great formations of the earth. In one respect, however, a very marked difference will be observed,—namely, that whereas the formations of the moon seem to have retained their forms, dimensions, and character almost intact, as if they had only recently arisen, those on the earth are more or less completely ruined, having been much disintegrated, and being everywhere covered with *débris*, which usually nearly completely fills up all the depressions and cavities they had produced. The origin of this difference in condition is not difficult to see: the terrestrial formations have been ruined by the action of the great amount of water yet present on the terrestrial surface, and principally from the action of rain, which, falling everywhere, has gradually worn the formations down and filled them up by the *débris* produced. In the course of this action there must have disappeared much of the water which the earth must have originally had free upon its surface in the form of oceans, seas, rivers, streams, and aqueous vapour, it being now locked up by absorption in the upper-lying strata of the terrestrial crust. It has been calculated that nearly one-half of the water originally upon the surface of the earth has disappeared from the oceans and rivers, and been absorbed into the rocks and other material forming the crust of the earth.

Turning now to the moon, it is soon apparent that on its surface there are to be found neither oceans nor rivers; if there be any water on the lunar surface it must be in the form of aqueous vapour, and even then the quantity must be very small. If the moon had oceans, seas, rivers, what has become of them? Their absence will account for the more perfect condition of the lunar formations, for without them there can be no rain; but why should the earth have had oceans, seas, rivers, and the moon none? Further examination of the lunar surface supplies the probable answer to these questions. More critical examination shows numerous indications of the action of some disintegrating agent like water—like rain. It soon becomes evident that, though the lunar formations have not been more or less completely ruined, like those of the earth, yet they have by no means escaped all disintegration. Everywhere appear formations, especially those obviously of more ancient character than the greater number now visible, that have undergone exactly the same kind of disintegration, and have reached the same state of ruination which is universal upon the earth. We are not justified, therefore, in assuming that the moon has never had any disintegrating agent like the terrestrial oceans, rivers, and rains; in fact, further study will lead to the conviction that in times gone by there must have been such upon the moon. Then naturally arise the questions, Where are they? What has become of them? Why have they disappeared?

The answer is, they have been completely absorbed in the upper-lying strata of the lunar surface, in exactly the same manner as the upper-lying strata of the terrestrial surface has absorbed so great a part of the primitive terrestrial oceans. The primitive lunar oceans would probably bear the same proportion to the mass of the moon as the primitive terrestrial oceans did to the mass of the earth. As the mass of the moon is only 1 ÷ 81·40 of that of the earth, so would the amount of water in the lunar oceans be only about 1 ÷ 80·4 of the amount of water in the terrestrial oceans; but the surface of the moon is fully 1 ÷ 13·5 of the surface of the earth, so that for each square mile of surface upon the moon there would be only 13·5 ÷ 81·4, or 0·166 part of the amount of water that existed upon the earth: in other words, upon the moon there would be six times as much surface to act upon a given quantity of water as there would be upon the earth. As the crust of the earth has shown itself capable of absorbing nearly half the primitive terrestrial oceans, it is easily understood how the six times greater proportionate amount of surface has enabled that of the moon to absorb the entire amount of the primitive lunar oceans. This absorption would have taken place long ago, and so put a stop on the moon to the process of disintegration, which has continued to the present day on the earth, and has thus produced the much greater effects which we find. On the moon, therefore, we find neither oceans, seas, nor rivers, neither clouds nor rain; because the lunar surface has absorbed all the water which formed the primitive oceans, seas, and rivers, and furnished the clouds and rain of the moon in its earlier days.

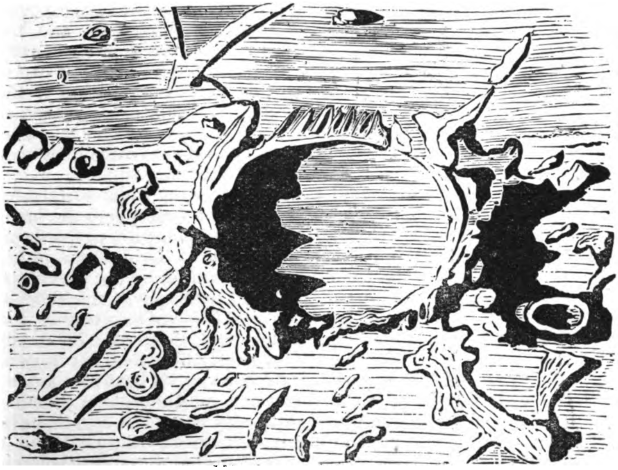


FIG. 56.—THE WALLED-PLAIN PLATO.

Has the moon an atmosphere? It is certain that it has not an atmosphere of the same density at the surface as the atmosphere of the earth. Such an atmosphere would reveal its presence in many ways, but principally in the refraction of the rays of light passing near the edge of the moon which it would produce at the times of solar eclipses and during the occultations of stars. But the force of gravitation at the surface of the moon is only one-sixth of the force at the terrestrial surface, so that any atmosphere on the moon would be condensed far less than on the earth, and would occupy far greater volume—more than eight times the volume. Moreover, as it would probably bear the same proportion to the mass of the moon as the terrestrial atmosphere bears to the mass of the earth, as we have seen in the case of the seas, it would have to be spread over more than six times the amount of surface. For this reason, even if the moon and earth had the same proportionate amount of atmosphere, the greatest density of the lunar atmosphere would be only one-fiftieth of that of the terrestrial atmosphere. Careful observations have shown that any atmosphere possessed by the moon cannot exert a refraction at the edge of the moon of more than two seconds of arc; and it is, therefore, certain that the lunar atmosphere has its greatest density less than two-hundredths of the density of the terrestrial atmosphere. It is probably, however, somewhat less dense than this: and the observations would lead to the conclusion that the greatest density of the lunar atmosphere was only 1 ÷ 350 of the greatest density of the terrestrial atmosphere. Despite this very small density, the relative mass of such an atmosphere would be very considerable, as its greater volume would counterbalance its lesser density. This atmosphere would—it will readily be understood—be capable of very sensibly affecting the physical condition of the lunar surface.

Owing to the sun shining continuously upon the lunar surface for nearly fifteen days at a time, were it not for an atmosphere the lunar surface would acquire a very considerable temperature, probably as much as 500° centigrade. From experiments by Lord Rosse, it has been concluded that the real temperature acquired by the lunar surface does not exceed a fourth of this, the atmosphere shielding it. Even this is very likely an exaggeration, and it is not improbable that the actual temperature of the lunar surface may not exceed 70° to 80° centigrade. Similarly, during a night of nearly fifteen of our days in length, the moon is continuously radiating away its heat into space; and it has been calculated that were there no atmosphere the temperature of the lunar surface would fall to an enormous degree, until it was far colder than anything ever known on the earth; to a temperature of − 200° centigrade. Yet the presence of this voluminous atmosphere completely alters this, despite its small density; for it would entirely shield the moon from directly radiating away its heat into space. Accepting even the experiments of Professor Tyndall on the absorption of radiant heat, it follows that all the heat radiated by the moon, after its temperature had fallen to 0°, would be absorbed by the atmosphere, and so the temperature of the surface would never fall much below zero. The experiments of other investigators on the absorption of radiant heat by gases would still more strongly confirm this view. The temperature of the lunar surface, therefore, probably ranges between 80° centigrade and −20°,—a conclusion in accord with Lord Rosse's experiments on the temperature of the moon. Of course, in regions near the lunar poles the temperature would never rise nearly so high as 80° centigrade.

The entire visible surface of the moon may be divided into three great classes, under which the whole of the diversely constituted

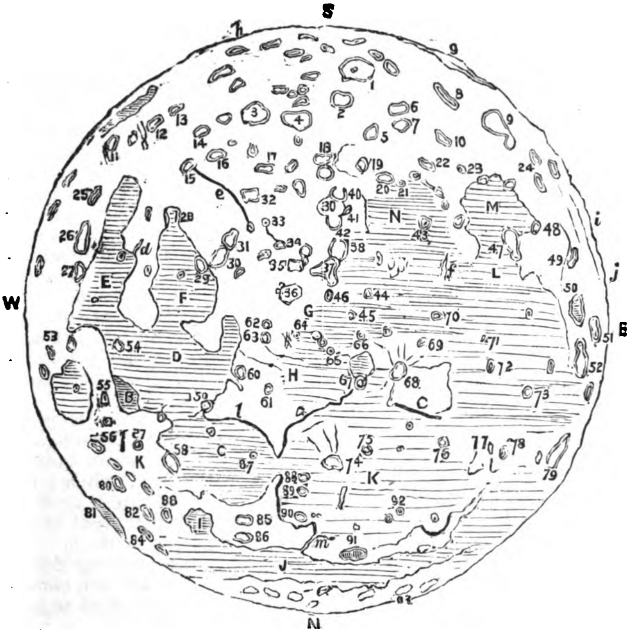


FIG. 57.—MAP OF THE MOON SHOWING PRINCIPAL FORMATIONS.

A	Mare Crisium.
B	Palus Somnii.
C	Mare Serenitatis.
D	Mare Tranquillitatis.
E	Mare Fœcunditatis.
F	Mare Nectaris.
G	Sinus Medii.
H	Mare Vaporum.
I	Lacus Mortis.
J	Mare Frigoris.
K	Mare Imbrium.
L	Oceanus Procellarum.
M	Mare Humorum.
N	Mare Nubium.
O	Sinus Iridum.
a	Apennine Mts.
b	Caucasus.
c	Carpathians.
d	Pyrenees.
e	Altai Mts.
f	Riphaen Mts.
g	Doerfel Mts.
h	Leibnitz Mts.
i	Corderillas.
j	D'Alembert Mts.
k	Taurus Mts.
l	Hæmus Mts.
m	Alps.
1	Clavius.
2	Maginus.
3	Maurolycus.
4	Stöfler.
5	Tycho.
6	Longomontanus.
7	Wilhelm I.
8	Schiller.
9	Schickhardt.
10	Hainzel.
11	Furnerius.
12	Metius.
13	Fabricius.
14	Riccius.
15	Piccolomini.
16	Zagut.
17	Apianus.
18	Walter.
19	Hell.
20	Pitatus.
21	Hesiodus.
22	Capuanus.
23	Ramsden.
24	Vieta.
25	Petavius.
26	Vendelinus.
27	Langrenus.
28	Fracastorius.
29	Theophillus.
30	Cyrillus.
31	Catharina.
32	Sacrobosco.
33	Almanon.
34	Albufeda.
35	Albategnius.
36	Hipparchus.
37	Ptolemy.
38	Alphonsus.
39	Purbach.
40	Regiomontanus.
41	Thebit.
42	Arzachel.
43	Bullialdus.
44	Lalande.
45	Mosting.
46	Herschel.
47	Oassendi.
48	Mersenius.
49	Sirsalis.
50	Grimaldi.
51	Riccioli.
52	Hevelius.
53	Condorcet.
54	Taruntius.
55	Proclus.
56	Cleomedes.
57	Romer.
58	Posidonius.
59	Plinius.
60	Julius Cæsar.
61	Manilius.
62	Godin.
63	Agrippa.
64	Triesnecker.
65	Bode.
66	Gambart.
67	Eratosthenes.
68	Copernicus.
69	Reinhold.
70	Landsberg.
71	Encke.
72	Kepler.
73	Marius.
74	Archimedes.
75	Timocharis.
76	Euler.
77	Aristarchus.
78	Herodotus.
79	Struve.
80	Messala.
81	Mare Humboldtanius.
82	Atlas.
83	Hercules.
84	Endymion.
85	Eudoxus.
86	Aristoteles.
87	Linne.
88	Autolycus.
89	Aristillus.
90	Cassini.
91	Plato.
92	Helicon.
93	Pythagoras.

lunar surface may be grouped. These are the ***plains***, ***mountains***, and ***craters***.

The first class, which occupies more than one half of the entire lunar surface, may be divided into the two great sub-classes of ***dark*** and ***light*** plains. The first includes the lunar ***seas***, or ***maræ***, and the latter includes a smaller class of level plains generally elevated considerably above the rest of the surface. Under the single term ***crater*** we may group the entire series of lunar formation, which, when seen under a low power in a small telescope, have been thought to resemble in appearance the terrestrial volcanoes. These may be divided into ***walled-plains***, ***ring-plains***, ***craters***, ***craterlets***, ***crater-pits***, and ***depressions***. Lastly, the class of mountains may be roughly divided into ***mountain chains***, ***highlands***, ***mountains***, ***ridges***, and ***hills***; though as on the earth there exist on the moon nearly every kind of elevation, such as here would be called mounds, hillocks, rocks, land-swells, etc.

Maria.—This term was applied by Hevelius to denote the great comparatively level plains of the moon, which exhibit considerable resemblance to the beds of dried-up oceans or seas, though even in his time they were known not to be covered with water. These great tracts are at full moon distinctly visible to the naked eye as dark-grey spots, in places sharply separated from the purer light of the brighter portions, but in others gradually fading into them. Examined closely, they are seen to be crossed by numerous long ridges, mostly of insignificant height, and to contain many hills and crater-pits. The maria are generally bordered by lofty ranges of rugged cliffs, broken here and there by ravines, indented in places by bays and gulfs, and projecting at others into long promontories. At other times the border is formed either by gently rising slopes, or by long series of low parallel ridges. When attentively scrutinised, many traces can be detected of erosion and disintegration all round these coast-lines, and frequent evidences of alluvial deposits can be clearly perceived, all pointing to the fact that in these dark-grey maria we find the dried-up beds of the ancient lunar oceans. These maria constitute about two-fifths of the entire lunar surface. They are most numerous in the north and east, smaller towards the centre and west, and entirely absent from the south. They are named after fanciful properties, as the Mare Vaporum (sea of vapours), Mare Nubium (sea of clouds), etc. The principal are the Oceanus Procellanum, and the Mare Imbrium, Mare Serenitatis, and Mare Tranquillitatis. They are usually from 300 to 500 miles in diameter.

Terræ.—These constitute the bright plains upon the moon, and consist of large tracts of tolerably level surface, broken here and there by low mountains and hills, and containing in places small ring-plains and crater-pits. They are not conspicuous, and disappear on all sides into the surrounding more rugged districts. They may be compared with the more level regions of the earth. None bear distinctive names.

The Mountains.—The larger mountains on the moon are generally to be found in the form of great masses of highlands, consisting of numerous groups of mountains united by short massive arms, and enclosing broad elevated plateaux, whilst here and there rise exceedingly lofty peaks. These highlands are crossed by numerous winding valleys and ravines, and contain numbers of rounded valley-like depressions, taking at times the appearance of craters. They are generally much brighter than the lower-lying districts, and often form the borders to the dark plains; in this case they often rise at their edges into great chains of lofty peaks. Some of these great highlands extend for several hundred miles in length, are a hundied miles or so in breadth, and contain peaks rising 10,000, 15,000, and 20,000 feet above the surface beneath them. At other times the mountains form long chains of lofty peaks, united together by a lower-lying continuous crest. They often enclose lower-lying tracts of more level country, giving rise to the formations known as *walled-plains*. Several of these great ranges of mountains extend for several

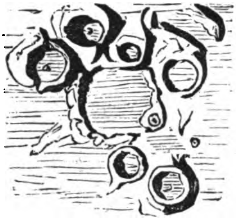


FIG 58.—FORMATION NEAR MOSTING. LOW POWER.

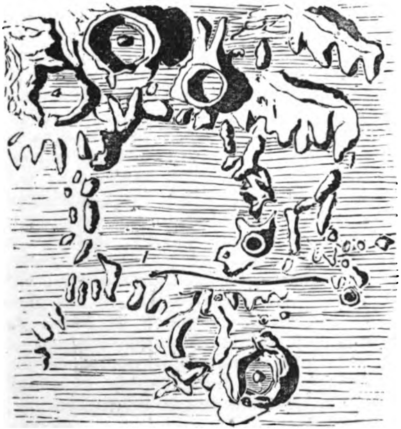


FIG. 59—FORMATIONS NEAR MOSTING MODERATE POWER.

hundred miles in length, and near the limb of the moon there are a number containing peaks of very great altitude, their summits towering 25,000, 30,000, and even 35,000 feet above the surrounding regions, thus far exceeding in height the loftiest terrestrial mountains. Isolated mountains of any height are not common, but hills ranging in elevation from 500 to 3000 feet are very numerous. The lower-lying portions of the surface, and especially the dark seas, contain numerous long winding ridges, usually several miles wide, and rising in gentle slopes to a height of from 200 to 2000 feet. Occasionally peaks on these ridges are still higher. The larger of these mountains are named after fancied terrestrial analogies in the Alps, Apennines, Pyrenees; most of them, however, are not named.

The Craters constitute a very diversified series of formations, most of which, when attentively examined, are found to bear no resemblance to terrestrial volcanoes. Fig. 58 (p. 141) shows a portion of the surface of the moon near the ring-plain called *Mösting*, as seen with a low power, and it will be observed that it seems to consist of a number of circular depressions resembling volcanic craters. Fig. 59 shows the same region under a higher power; and it will be seen at once that the crateriform character of several of these so-called *craters* has disappeared, their true nature as mere plains surrounded by hills, ridges and mountains being distinctly visible. The diameter of the great central enclosed plain—or Walled-plain as it is called—is fifty miles, whilst the surrounding elevations reach a height of from 1000 to 3000 feet. A similar instance is furnished by the great ring-plain Copernicus. Seen as in fig. 60 (p. 143), under a low power, it looks much like the crater of some gigantic volcano, for its diameter is fifty-six miles, but examined under a higher magnifying power, this resemblance in great part disappears. How utterly dissimilar these formations are from the craters of volcanoes would be shown by a section of Copernicus, where it would be seen how comparatively low the walls are, and what gentle slopes they possess. Yet the actual height of the walls is 10,000 feet; but then their breadth is 110,000 feet. These formations, though possibly they have their origin in some form of volcanic energy, or rather perhaps in the same internal forces which give rise to the true volcanoes, are entirely different in character to the terrestrial volcanoes. They rather resemble the great enclosed valleys not uncommon on the earth. Such formations are common in North America and in Europe. Bohemia may be taken as a representative instance. And though viewed from above the walled-plains resemble great mountain rings, viewed from the lunar surface it would be only with difficulty that this character would be recognised.

The principal walled- and ring-plains on the moon are named after celebrated astronomers, as Plato, Archimedes, Copernicus, Newton, Herschel, etc.

The larger formations of the moon of this class are the *walled-plains*, which range in diameter from 40 to 160 miles, and resemble mere level tracts of surface enclosed on all sides by very irregular broad masses of mountain ranges, frequently rising in places into peaks of from 10,000 to 20,000 feet in height. Of smaller size and more regular form are the *ring-plains*, which range in diameter from twenty to sixty miles, and possess broad walls reaching at times to an elevation of 15,000 feet above the interior, though seldom as much above the surrounding surface—for it is a noteworthy thing in connection with these ring-plains that the interior is much below the level of the exterior. The walls of the ring-plains are much terraced, and are generally ten times as broad as they are high. The *craters* are somewhat similar in appearance to the more regular ring-plains, but are smaller, seldom exceeding ten miles in diameter, and are everywhere surrounded by a highly disturbed rugged surface, having all the appearance of being volcanic in nature. Round about the principal craters are usually to be found many bright minute crater-cones, about 1000 feet in height, and with a crateriform orifice some half a mile or so in diameter. These small crater-cones seem to be the true representatives of our terrestrial volcanoes, just as the

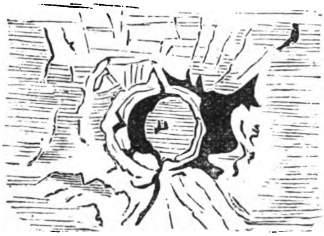


FIG. 60.—THE RING-PLAIN COPERNICUS, AS SEEN WITH SMALL MAGNIFYING POWER.

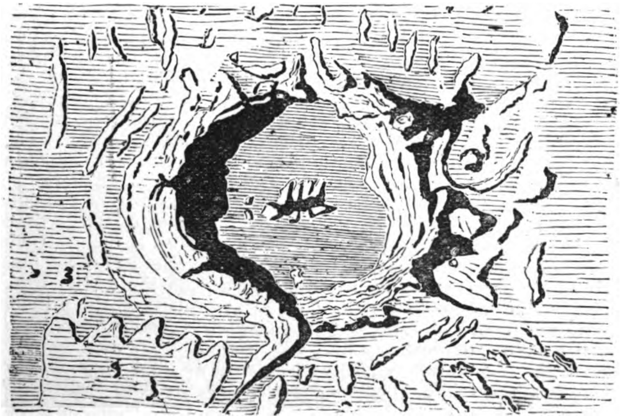


FIG. 61.—THE MOON: THE RING-PLAIN COPERNICUS.

larger *craters* would seem to correspond to the large but now extinct craters of the earth. The smaller of the craters are called *craterlets*. By *crater-pits* are meant the small crateriform-looking formations so abundant on the moon resembling small shallow cup-shaped, or rather saucer-shaped, depressions, which are not easily distinguished from the true *craterlets* at a first glance, but differ from them in the very slight slope of their walls, and in being extremely shallow, as they are often not more than a hundred yards deep, though several miles in diameter. In some portions of the moon these formations seem to cover the surface, but they disappear from view within a few hours after they become visible. They have nothing of the crater nature about them, but correspond to the shallow depressions and dimples so common on the earth. Without exaggeration, it may be said that the greater number of them would altogether be invisible as depressions to any one placed in their centre.

The last class of lunar formations which need be referred to is that whose members are called *rills* or *clefts*. These resemble long canals with parallel banks, varying in width from 1000 to 3000 feet, and in depth from 100 to 500 feet, whilst in length they vary between 10 and 400 miles. They mostly seem to be connected with the systems of valleys, traversing the mountain region, whilst they themselves usually run along the lower-lying more level districts. They are usually either straight or but slightly curved ; occasionally they end in some definite manner, as at the mouth of a valley or break in a walled-plain, but usually they disappear insensibly. At times they seem to cut through all intervening objects, but at others to be interrupted by mounds or craters, only to reappear beyond and pursue their course in the same direction as before. The origin of these peculiar formations is unknown, or even what is their nature, but they seem to have at times acted as river beds ; though this has been probably merely an accident due to their favourable position. These *rills* will be found shown on the drawings of both the *Apennines* and on the region near *Mösting*.

The conclusions to be drawn from a careful study of the lunar surface, therefore, is that the moon, though no copy of the earth, has been moulded by the same forces, but in a modified manner. Owing to the smaller force of gravity, the volcanic energies have been manifested on a larger scale upon the moon than on the earth ; whilst, owing to the more rapid and complete absorption of the primitive oceans and seas, the process of disintegration and erosion on the moon have not reached anything like the advanced state found on the earth. In these respects, therefore, we find very different conditions prevailing upon the surface of the two bodies. The absence of water necessitates the absence of both clouds and rain, and, therefore, of vegetation, or rather of such luxuriant vegetation as is found on the earth. It is not improbable that some kind of vegetation may exist upon the moon, especially within the deeper valleys and ring-plains, where it would to a certain extent be shielded from the sun. Some moisture may be present in such places, to be liberated when the sun is high, and deposited as dew and reabsorbed by the surface during the lunar night. And it is noteworthy that certain periodical changes in colour have been observed in such situations, and have been thought to be indications of the existence of such vegetation.

It has been thought very probable that the volcanic energies of the moon are no more extinct than those of the earth; and several instances of supposed changes on the moon have been suspected, and more or less certainly established. The search for such changes, and the study of the conditions under which they occur, is not the least important branch of selenography, and may be expected to throw much light on the past history and future career not only of the moon but of its primary the earth.

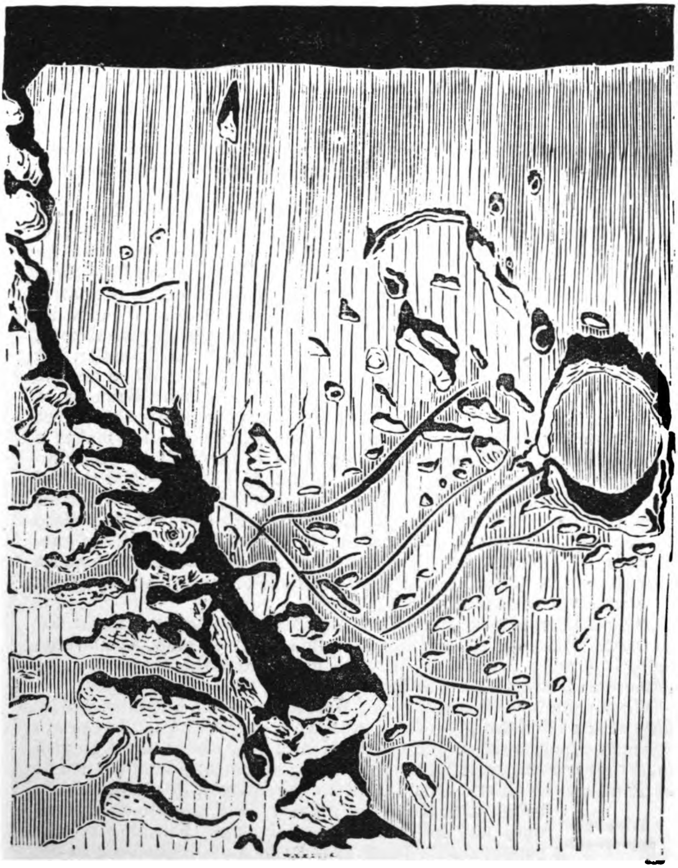


FIG. 62. THE APENNINES AND WALLED-PLAIN ARCHIMEDES.

CHAPTER XVI.

MARS AND THE MINOR PLANETS.

Mars—Dimensions—Telescopic Appearance—Cartography—Atmosphere—Polar Snow Spots—Physical Condition—Satellites—Existence of other similar Bodies—The Minor Planets.

MARS.—Of all the planets Mars is the one which is the most favourably placed for observation; for, though it does not approach the earth quite so closely as does Venus, yet when it is near the earth it is remarkably well placed for examination, shining in the midnight sky like a miniature full moon, with a brilliancy second to none; whereas Venus, when nearest the earth, turns towards us its unilluminated side.

Dimensions.

In figure Mars resembles the earth, being a spheroid departing very little in form from a sphere. its ellipticity being about 1 ÷ 250, or a little greater than in the case of the earth. The polar diameter of the planet is 4215 miles, and its equatorial diameter 4233—these corresponding, when at the same distance as the sun from the earth, to apparent diameters of 9·36″ and 9·40″. When at its farthest distance from the earth, the planet resembles in appearance a tiny circular reddish disc scarcely 4″ in diameter, but in opposition it has a mean diameter of nearly 20″. When nearest the earth, as at very favourable oppositions, the real diameter of Mars is as large as 26″. As under these circumstances the planet shines like a brilliant disc against the dark sky, irradiation makes it look still larger, this increase varying from 4″ in small telescopes to 1·5″ in large ones. The mass of the planet is 1 ÷ 3,090,000 that of the sun, or scarcely a ninth of that of the earth; and as its diameter is rather larger than half that of the earth, it follows that its surface is less than three-tenths of that of the earth, its volume less than one-sixth, and its density less than two-thirds, or only about three and a half times that of water. On Mars the force of gravity is only about four-tenths of what it is upon the earth.

The planet rotates upon an axis inclined at an angle of about 60° to the ecliptic once in 24 hours 37 minutes 22·6 seconds,—this value being tolerably certain, it being deduced from the comparison of numerous drawings made at intervals during over two centuries.

Telescopic appearance.

When examined in a telescope, Mars appears like a reddish-yellow disc with a few faint greyish or greenish-grey markings. As the eye becomes experienced in the observation of this planet, these greyish markings become much more easily seen, and a considerable amount of detail can be observed on the disc of the planet, its whole surface being marked out by greyish shadings into an appearance not unlike a terrestrial map. For long it was supposed that these grey spots were only clouds in the atmosphere of the planet, but of late years it has been shown that they are permanent features, and they are with much probability regarded as showing the position of the planetary seas and oceans. If this view be correct, the proportion of land to sea is very different on Mars to what it is on the earth, for whereas on the latter the seas

Cartography.

predominate, on the former there is far more land than water. On Mars the waters seem to be distributed in numerous narrow seas and long inlets, which intersect the land in all directions and divide it into numerous islands separated from each other by narrow channels: that is, comparatively narrow, for it is doubtful if any of those which we can see have a less breadth than one hundred miles. Owing to the labours of Proctor, Terby, Burton, Schiaperelli, and Green, the configuration of the surface of Mars has been carefully mapped, and names have been assigned to the principal dark and light markings, the names being those of the principal observers of the planet.

A considerable number of other divisions have also received names, such as Kaiser Sea, running north from Dawes Ocean, and Hook Sea, to the south of Herschel Continent.

Some uncertainty, however, yet attaches to the smaller features shown on these maps, as it is only in powerful telescopes that they can be distinctly seen. Another difficulty is introduced by the clouds which from time to time form in the atmosphere of Mars, and cannot very easily be distinguished from the yellowish markings constituting the land. These clouds often mask even the larger and more distinct dark seas, and were the origin of the curious changes in the appearance of these darker markings which led to the earlier astronomers taking them for clouds they forgetting that though clouds seem to us on the earth to be grey, as we see the shadowed or underneath side, on Mars they would seem to us to be white, as we should see the upper illuminated surface.

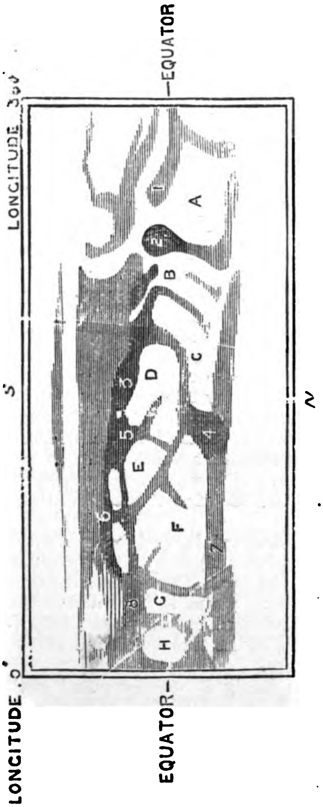


FIG. 63.—CHART OF MARS (Names according to Proctor and Green).

A Beer Continent. B Herschel Continent. C Fontana Land. D Secchi Continent, East, E Secchi Continent, Central. F Secchi Continent, West. G Mädler Continent. H Leverrier Land. 1 Herschel Strait. 2 Dawes Ocean. 3 Maraldi Sea. 4 Oudemans Sea. 5 Trouvelot Bay. 6 Funchal Bay. 7 Campani Sea. 8 De la Rue Ocean.

Atmosphere.

Polar snow spots.

From a number of observations it is probable that the atmosphere of Mars is but little different in density to that of the terrestrial atmosphere; and the very existence of seas, and of aqueous vapour (revealed by the spectroscope, according to Huggins, Janssen, and Tacchini), shows that the temperature of the planet cannot differ much from that of the earth; for were it less there would be no trace of aqueous vapour to be detected, and were it more this aqueous vapour would be so large in quantity that it would give rise to a permanent screen of clouds, as in the case of Venus. This atmosphere would not extend far from the surface of the planet, but, as in the case of the earth, it would form a shallow atmospheric envelope so rapidly decreasing in density that at a height of a hundred miles above the surface it would have become sensibly evanescent. Even when the planet was nearest the earth, the atmosphere would vanish at a distance of 0·4″ from the true limb, or within the limits of the spurious fringe due to irradiation. At the poles of the planet there are visible two rounded white spots, which are commonly supposed to be due to the snow and ice accumulated round the poles of the planet, and in support of this view it has been supposed that they wax and wane with the winter and summer seasons on Mars. At times similar isolated brilliant white spots have been seen near these polar caps, and on several occasions even in the equatorial regions of the planet. These white polar caps it has been supposed are not always exactly opposite each other, as they should be if they marked the position of the polar snows, and they are not always circular in form. Some observers have therefore supposed them to be floating masses of ice. It is not improbable that they may be permanent polar strata of clouds, which would vary in shape, position, and form, not only with the seasons, but in a minor manner with the set of the winds and meteorological conditions of the year.

Physical condition.

From this account it will be evident that the condition of the planet Mars is not very different from the condition of the earth, the difference being more in degree than in kind; and it is probable that a persevering study of the features presented by this planet may do much to gain us further real knowledge of the true condition of the other smaller planets of the solar system.

Satellites.

Until quite lately it was supposed that the planet Mars had no satellite, but in the summer of 1877 astronomers were electrified by the announcement telegraphed from America that Professor Asaph Hall had discovered two small satellites. They were discovered with the magnificent 27-inch telescope at the Washington Observatory; but, as is usually the case, once discovered they were easily seen with far smaller telescopes, Wentworth Erck having easily seen the outer satellite with a 7⅓-inch telescope.

These two satellites have been named *Deimos* and *Phobos*, the former being the outer satellite and the one most easily seen, though the latter is probably both slightly larger and a little more brilliant, but being so much nearer to the brilliant planet it is not so easy to see. *Deimos* is distant from the centre of Mars by 32·3″ and its period of revolution is 30 h. 17 m. 53·9 s., and for *Phobos* these quantities are 12·9″ and 7 h. 39 m. 14·0 s., the planet's diameter being taken as 9·4″.

These two moons are the smallest known members of the solar system, with the exception of the meteors—being far smaller than the smallest minor planets. According to the American observers their real diameters are only about six and seven miles respectively; but this is probably much under-estimated, and their real diameters will not unlikely turn out to be about fifteen and twenty miles respectively. The discovery of these bodies opens a new field for research, for if Mars has satellites so small as this, it is not impossible that other of the planets may have similar bodies revolving round them. Even in the case of Venus, such bodies would be very difficult to see even if thirty or forty miles in diameter; and closer scrutiny may yet show one or more satellites revolving round both Venus and Mercury. Similar bodies may also be moving round the larger minor planets—as for instance *Vesta*, *Pallas*, or *Ceres*. Moreover, it is not improbable that yet other satellites to Mars may be discovered when the planet next comes into opposition under exceptionally favourable conditions, as it will in the year 1892.

Existence of other similar bodies.

THE MINOR PLANETS.—With the exception of the form and dimensions of their orbits and their motions therein, we know scarcely anything of these bodies except their brightness, which ranges from the sixth magnitude down to the fourteenth or even below. Even in the largest telescopes they are not to be distinguished in appearance from the ordinary stars of the same brightness, and of their physical conditions we know absolutely nothing. From their brightness we may form some idea of their probable dimensions. The three largest appear to be *Pallas*, *Ceres*, and *Vesta*: their diameter may be taken as about 300 miles; then come *Juno*, *Hebe*, and *Iris*, all about 150 miles in diameter. From these dimensions they gradually descend to very much smaller proportions, many being under fifty miles in diameter. In number they amount to about 250, but there can be no doubt that there are at least several hundred not much smaller ones which could be discovered by a systematic search. But so numerous has been the discovery of these bodies of late years that the events have lost all importance and much of the interest which formerly attached to them. So many of them are now known that it has been found impossible to furnish adequate ephemerides for their observation: consequently several have not been observed for years, and one at least has been lost.

Dimensions.

All these bodies move in orbits between Mars and Jupiter, and principally with mean distances lying between the limits 2·10 and 4·00, but mostly near 2·4, 2·7 and 3·0. In the greater number of cases the orbits are neither much inclined to the ecliptic nor very eccentric in form, but there are about twenty which have orbits very much inclined to the others, or else of great eccentricity. Several of the smaller minor planets seem to be associated in pairs, each having orbits of very similar size, form, and position,

CHAPTER XVII.

JUPITER AND SATURN.

Jupiter—Its Atmosphere—Its Dimensions—Its Rotation—Its Belts—Physical Condition—Satellites—Saturn—Figure and Dimensions—Rings—Satellites.

JUPITER.—Jupiter is the largest planet of the solar system, and of all the greater planets, the one most favourably placed for our study—it approaching us at times, when in opposition, to within four times the mean distance of the sun from the earth, and so enabling us distinctly to discern on its surface markings less than a thousand miles in diameter. When examined, the disc presented by Jupiter is seen at once to be an ellipse in shape, with axes in the proportion of 16 to 15, so that it is obvious that the planet is very spheroidal in form, the ellipticity being about 1 ÷ 15·7. This considerable ellipticity probably arises from the combined effect of the quick rotation of the planet conjoined with its large diameter. We do not see, however, the actual surface of the solid body of the planet, but only the uppermost of the cloud-bearing strata of its atmosphere. It has been supposed, therefore, by some astronomers that the true surface of the planet may lie very many miles beneath the cloud surface alone visible to us, and be far smaller in dimensions and less elliptical in form. But closer consideration shows that this cannot be the case, for, owing to the large diameter and greater power of gravity, the density of the atmosphere of Jupiter must so rapidly increase with the depth beneath the upper-lying strata of clouds, that at a distance of less than a hundred and fifty miles the atmosphere must be so condensed as to cease to be gaseous. It is true that the dense cloudbelts which we see on Jupiter, and the complex spectrum which is exhibited by the light it reflects to us, lead us to suppose that the temperature of the planet is far greater than the temperature of the earth—that, in fact, the lower-lying strata of the atmosphere and the true surface of the planet may be nearly white-hot; but even under these conditions the depth of the atmosphere of Jupiter cannot much exceed a hundred miles.

Its atmosphere.

When at its mean distance from the earth the equatorial diameter of Jupiter is 37·62″ and its polar diameter 35·16″, though, owing to the effect of irradiation, the apparent telescopic diameter of the planet is some 2″ larger. When in opposition, however, the diameter may rise to as much as 48″, and when at its greatest distance from us fall as low as 32″. It follows that the polar diameter of Jupiter is 82,380 miles and the equatorial diameter 88,140 miles, the mean diameter being 86,000 miles, or eleven times as great as that of the earth, so that in volume it exceeds the latter by over thirteen hundred times. The mass of Jupiter can be calculated with great certainty from the motion of its satellites, and is 1 ÷ 1047·8 that of the sun, or some 300 times as great as that of the earth. It follows, therefore, that the mean density of the planet is only about one-fourth of that of the earth—a confirmation of the view that the mean temperature of Jupiter is very much the

Its dimensions.

greater of the two, the entire body of the planet being probably still white-hot, and therefore far less dense than it otherwise would be.

Its rotation.

Jupiter rotates on an axis inclined very slightly to the perpendicular to its orbit, once in about 9 hours 55½ minutes, the exact period of its rotation being unknown, for it has been definitely ascertained that different objects on its surface rotate in different times, they being probably clouds floating in its atmosphere at different heights and moving with different velocities. Thus certain small white spots have been observed to rotate so quickly that they make a complete rotation once in $9^h\ 50^m\ 5^s$, whilst a great red spot which has been visible for the last eight years required $9^h\ 55^m\ 34{\cdot}5^s$ for a rotation. Other spots in the belts have in turn rotation-periods differing a little from either.

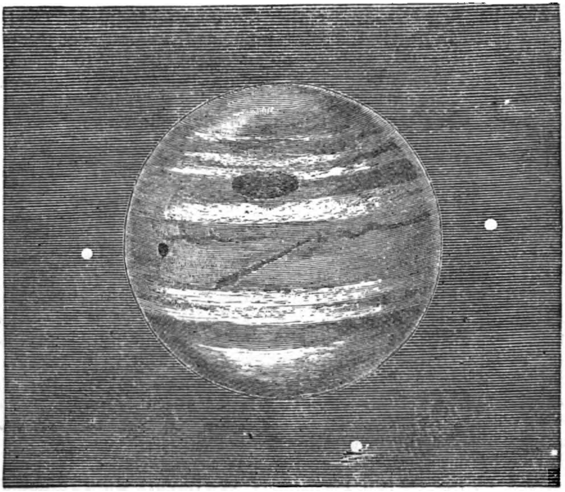


FIG. 64.

Its belts.

When viewed in a telescope, the disc of Jupiter is seen to be crossed by a broad equatorial belt of reddish hue, separated from the greyish polar regions by broad white cloud-belts. Frequently the broad equatorial belt is divided into two or more by narrow zones of white or grey clouds; and similarly at times the white cloud-belts of the temperate region are divided by narrow dark belts, usually yellowish or greyish in tint. The great equatorial belt is at times a very deep red in hue, but is more generally orange-brown in colour. On it are usually to be seen a number of greyish or white spots, whilst at times its whole surface is mottled with lighter hues. Dark grey, almost black spots, have frequently been seen in both the dark and bright belts, and yellow and red spots are not infrequent. All these appearances are very variable in character, and present the multitudinous varieties of form, shape, and mutability which we should expect in a highly disturbed atmosphere.

Physical condition.

All that is known of the appearance of the planet points to Jupiter being under very different physical conditions to the group of smaller planets of the solar system, and indicates that it is still an intensely heated, incandescent body, more or less completely veiled from our view by great masses of dense cloud floating in an atmosphere which is the scene of great whirlwinds, swift currents, and tremendous cyclones. And though probably a body of older birth than the earth, from its great mass and dimensions it has advanced far slower in its career as a planet, and in physical condition resembles the earth as it was long before the earliest epoch of geology.

Satellites.

Jupiter has four satellites, which move round it in almost circular orbits situated in nearly the same plane as the equator of the planet, which is inclined at an angle of 3° 5′ to the ecliptic. The satellites are distinguished by being numbered I. to IV. as one proceeds outwards. The mean distances in radii of Jupiter and the period of a complete sidereal revolution are as follows—

					d.	h.	m.	s.
I.	Distance	= 6·048	Period	=	1	18	27	33
II.	„	= 9·623	„	=	3	13	14	36
III.	„	= 15·350	„	=	7	3	42	33
IV.	„	= 26·998	„	=	16	16	31	50

These satellites usually shine like stars of the sixth magnitude, III. being the brightest and IV. the faintest; yet both III. and IV. are subject to great variations in this respect, sometimes being so faint that they can only be detected with some trouble. In consequence, though these satellites are usually not to be distinguished when in transit across the disc of the planet, owing to the little differences in brightness between the surfaces of the planet and satellite, yet at times they appear as dark spots when in transit. Many astronomers have suspected the existence of dark spots on these satellites, which would account for these variations in brightness.

It has been supposed that these dark transits of the satellites indicate that the central portions of the disc of Jupiter shine very much brighter than the edges; but it has been noticed that the satellite frequently appears dark up to the very moment it reaches the edge of the planet, and shines with much diminished lustre even when seen against the dark sky.

Dimensions of satellites.

These bodies are all large enough to have sensible discs in a telescope—discs due partly to the real dimensions of the satellites, and partly to irradiation, which augments the apparent diameter of all bright bodies. Their apparent diameters are—

I. = 1·10″ II. = 0·95″ III. = 1·60″ IV. = 1·50″;

so that their real diameters are about

I. = 0·75″ II. = 0·65″ III. = 1·20″ IV. = 1·10″;

and their dimensions in miles are—

I. = 1750 II. = 1500 III. = 2800 IV. = 2550.

The two outer satellites are therefore somewhat larger than the moon, whilst the two inner are somewhat smaller. It is not improbable that these satellites are surrounded by extensive atmospheres, which would produce considerable variations in their brightness according to the prevalence of clouds. It is these variations in meteorological conditions which probably give rise to the observation of variations in the visibility and form of the dark spots.

The phenomena presented by these satellites of Jupiter form one of the most interesting features in connection with the Jovian system; their transits across its face, their eclipses in its shadow, and their occultation by its body, all being the objects of numerous and important observations, which, when properly discussed, lead to valuable contributions to astronomy. The configuration of the satellites, and the times of the eclipses, occultations and transits of the satellites and their shadows, are given for each day in the "Nautical Almanac," so that these phenomena can be easily observed and the satellites identified.

Saturn.—From its unique system of rings, Saturn presents some of the finest phenomena visible in the entire solar system. These rings which encircle it, by their continual variation as the planet in its motion in its orbit causes us to view them more or less obliquely, give a wide variety to the appearance of Saturn, and in conjunction with the phenomena presented by the eight rapidly moving satellites, renders the planet a most striking object. As the principal features of the Saturnian system can be seen with even small telescopes, this planet is generally one of the most interesting bodies for those with only moderate instruments; and as for the next twelve years it will be favourably placed for observation, much will doubtlessly be learnt of the telescopic appearance of the planet, and in consequence of its probable physical condition.

Figure and dimensions.

The planet itself, or rather its ball as it is called, does not show much to even the most attentive telescopic scrutiny: all that can be detected are some faint equatorial greyish belts on the golden-yellow disc—indications of a physical condition somewhat similar to that of Jupiter—but the faintness of these belts would indicate that Saturn was still more buried in dense clouds than even its giant neighbour. In figure, Saturn is the most spheroidal of all the planets, its ellipticity being about 1 ÷ 11, the planet when at its mean distance from the earth having a polar diameter of 15·4″, and an equatorial diameter of 17·0″, its mean diameter being about 16·5″. In the telescope, owing to the irradiation, these quantities seem about 0·8″ larger. These dimensions correspond to 73,000 miles, 66,000 miles, and 71,000 miles respectively, so that the mean diameter of Saturn is about nine times as large as that of the earth, and its volume would be about 700 times as large. As the mass of Saturn, which is easily determined from the motion of its satellites, is 1 ÷ 3500 of the sun, or only rather more than 90 times that of the earth, it follows that the mean density of the planet can be only one-eighth of that of the earth or three-fourths of that of water. This would almost seem to indicate a very high temperature—even higher than that of Jupiter—though as probably the older and certainly the smaller planet, this is not what we should have expected. Saturn rotates on an axis inclined at an angle of 26°50′ to its orbit, or 28° 50′ to the plane of the ecliptic, once in 10 h. 14 m. 29 s. This determination, however, is very uncertain, for there are few well-marked spots visible from which to determine the true period of rotation.

Rings.

The magnificent ring system of Saturn consists of three broad flat rings of very slight thickness, and slightly elliptical in form, rotating once in about 10 h. 29 m. round the planet, which lies in one of the foci of the rings; the whole system being in nearly the same plane as the equator of Saturn. The outermost ring A has an apparent telescopic diameter of 39·9″, or a real diameter of about 39·4″ or 169,500 miles. It is separated from the brighter inner ring by a dark division, about 1″ wide, named after its reputed discoverer *Ball's division.* Lately, however, evidence has been adduced by Adams tending to show that Ball did not really discover this division, but that it was first described by Cassini. The outer diameter of this inner ring B is 34·4″ or 144,600 miles, its inner 26·3″ or 123,000 miles. It is brightest at its outer edge, and gradually fades away at its inner edge. In both these rings astronomers have observed a number of fine consecutive black markings, dividing as it were each ring into a number of small rings; but it is difficult to say how far these apparent divisions are real. The innermost or dusky ring C is much fainter than either of the others, and is partially transparent, so that the limb of Saturn can be perceived faintly through it. Its inner edge is distant about 2″ from the edge of the ball, so that its inner diameter is 21·0″ or 100,000 miles. The thickness of the ring is less than 0·1″ or 400 miles. Many speculations have been hazarded as to the probable nature of these rings, but it would seem most probable that they are zones

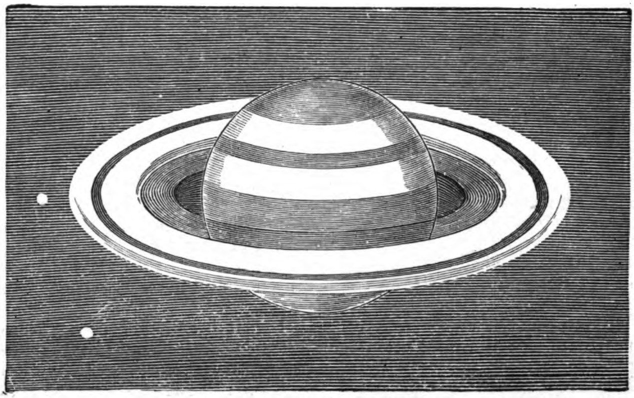


FIG. 65.

of minute satellites, each perhaps fifty miles in diameter, and separated from each other by six or seven times this distance in the brighter rings, and rather more in the dusky ring. These satellites would, not unlikely, be surrounded by considerable atmospheres, which, joining one another, would cause the entire rings to be enveloped in a gaseous medium, which might be the source of many of the variations in brightness which have been noticed in the rings.

The mass of the rings is probably less than one five-hundredth of the mass of the planet itself. The plane of the rings makes an angle of 28° 10·6′ with the plane of the ecliptic, and its ascending node is in longitude 167° 55′.

Saturn has at least eight satellites, seven of which move in orbits in the same plane as the rings, whilst the most distant moves in an orbit much inclined to the plane of motion of the others. The names, distances in radii of Saturn, and periods of these satellites, are as follows :—

Satellites.

				d.	h.	s.	m.
1. Mimas	Distance	3·36	Period =		22	37	23
2. Enceladus	,,	4·32	,, =	1	8	53	7
3. Tethys	,,	5·34	,, =	1	21	18	26
4. Dione	,,	6·84	,, =	2	17	41	9
5. Rhea	,,	9·55	,, =	4	12	25	11
6. Titan	,,	22·15	,, =	15	22	41	25
7. Hyperion	,,	26·78	,, =	21	7	7	40
8. Iapetus	,,	64·36	,, =	79	0	8	36

The innermost of these satellites, *Mimas*, moves in an orbit so close to the planet that it never moves very far from the rings, and owing to its proximity to these bright objects it can only be seen with great difficulty, though it probably is bright enough to shine like a 12th standard magnitude star. Its diameter is therefore about 600 miles, or less than half of that of the smallest satellite of Jupiter. *Enceladus*, from its greater distance from the planet, is far easier to see, though it is probably but little larger or brighter than Mimas. *Tethys* would seem to be considerably larger than either of the inner satellites,—probably about 1000 miles,—so that it shines like a star of about the 11th magnitude, and from its distance from the planet can be readily seen in telescopes of moderate aperture, four inches being ample on favourable occasions. *Dione* and *Rhea* are still brighter, shining like stars of the 10½th and 10th magnitude, and are readily visible in even small telescopes ; they are about 1300 and 1400 miles in diameter, or about the size of the smaller satellites of Jupiter. *Titan* shines like a star of the 8th magnitude, and is probably 3500 miles in diameter—considerably larger than even the III satellite of Jupiter, and approaching Mars in dimensions. *Iapetus* is probably little inferior to Titan in size, but is not so bright ; it is moreover very variable in brightness —at times, when in the western portion of its orbit, shining like a star of the 8½th magnitude, and at other parts of its orbit fading away till only of the 11th magnitude. It moves, too, in an orbit inclined at an angle of nearly 12° to the plane of the orbits of the other satellites. Between these two larger satellites, but much nearer Titan, comes *Hyperion*, a minute satellite shining like a star of the 13½th magnitude, and probably only 300 miles in diameter, so that it can only be seen in powerful telescopes, at least eight inches aperture being required.

It is not unlikely that there are other small satellites in the great gap between Titan and Iapetus, and not improbably also between Rhea and Titan. If so, they cannot be much larger than Hyperion, and are most likely even smaller, or between 200 and 400 miles in diameter. From their considerable distance from the planet and extreme faintness, these bodies would not be readily detected, and no systematic search for them seems to have been made. From the strange discordance in the observations of Hyperion, it is not unlikely that at times another similar satellite may have been seen and mistaken for this body. There may also be satellites interior to Mimas, but if so their proximity to the planet would render it excessively difficult to see them even in the finest telescope; still if the rings are really great groups of small satellites, it is not unlikely that one or more of such bodies may really exist and be detected at some future period.

CHAPTER XVIII.

URANUS, NEPTUNE, AND ULTRA-NEPTUNIAN PLANETS.

Uranus — Dimensions — Satellites — Neptune — Dimensions — Satellite — Ultra-Neptunian Planets—Their Discovery.

URANUS.—Owing to its great distance from the earth, very little can be made out on Uranus even in the most powerful telescopes: some observers have indeed fancied that they could detect very faint bands and spots, but it is difficult to say how far they are real. Probably the planet is spheroidal in form, but the amount has not yet been determined with any certainty, nor even the exact position of its poles, though the approximate direction of its axis is ascertained by assuming that it is at right angles to the plane of the motion of its satellites.

It is supposed, therefore, that the equator of Uranus is inclined at an angle of 97·8° to the ecliptic, and that the ascending node of its equator is in longitude 165·5°, whilst its axial rotation is probably about 12 h.

Dimensions.

The telescopic diameter of Uranus is about 3·8″, which would correspond to a real diameter of about 3·3″—that is, to 28,500 miles, or about three and a half times that of the earth, so that its volume would be rather more than forty times as large. From the motion of its satellites, it would appear that its mass is only 1÷23,000 times that of the sun, or fourteen times greater than that of the earth; so that the mean density of Uranus would be only one-third of the mean density of the earth, or rather less than twice that of water. It is probable that the physical condition of the planet resembles in all essential characters that of Jupiter.

The great inclination of its axis of rotation, if it be really perpendicular to the plane of the orbit of its satellites, will, however, give rise to enormous seasonal changes, since the duration of both day and night must vary in length from only a few hours to many years, as the planet moves in its orbit. The influence of such variations must be very great.

Uranus possesses four satellites, whose names, distances in mean radii of Uranus, and periods, are :—

Satellites.

					d.	h.	m.
I.	Ariel	Distance	7·2 = 13″·8	Period =	2	12	28·8
II.	Umbriel	„	11·5 = 19·2	„ =	4	3	27·6
III.	Titania	„	18·9 = 31·5	„ =	8	16	56·4
IV.	Oberon	„	25·3 = 42·1	„ =	13	11	6·6

The two outer satellites are not very difficult to see, being about 12½ standard magnitude, but owing to their proximity to the planet they appear about half a magnitude fainter. Under favourable circumstances they can be easily seen with telescopes of about nine inches aperture. They are probably about 2000 miles in diameter. The two inner satellites are much fainter, probably not brighter than 14th magnitude, and very difficult to see, as they are never far from the planet. Their real diameter is probably less than 1000 miles.

Dimensions.

NEPTUNE.—The history of the discovery of this planet has been already narrated, and since its discovery nothing new has been made out about either the form, dimensions, or physical condition of the planet, as its distance renders it a minute faint object even in the largest telescopes. Its apparent diameter at its mean distance would seem to be about 2·6″, which would correspond to a real diameter of some 2·0″ or 27,000 miles. The mass of the planet, which is the only factor determined with certainty, is 1÷19,000 of that of the sun; so that in density, as in dimensions, it is closely analogous to Uranus.

Satellite.

The only satellite of Neptune which has yet been discovered moves round the planet once in 5 days 21 hours 3·0 minutes, at a mean distance of 8·1 radii of the planet, or 16·2″. Like the satellites of Uranus, its orbit is inclined at more than a right angle to the ecliptic, the inclination being equal to 145·1° and the longitude of the node being 184·5°. In brightness it shines like a standard 12th-magnitude star, so that its size must be very considerable, probably over 6,000 miles in diameter. It is therefore the largest body of its class, and in dimensions resembles the inner planets of the solar system—being larger than Mars, and not much smaller than Venus. It is not unlikely that there are other satellites as yet undiscovered.

Ultra-Neptunian planets.

Is Neptune the outermost planet of the solar system? That is a question which has at different times excited a considerable deal of speculation in the minds of astronomers. It will be remembered that Neptune was discovered from the perturbations which its attraction caused in the motion of its neighbour Uranus. Hence arises the question—Does Neptune exhibit similar irregularities in its motion? As far as we know at present the answer must be—No. But then the answer is not conclusive, for Neptune has not been properly observed for a sufficiently long time to enable us to feel sure. Two hundred years hence it will be possible, by the investigation of the actual motion of Neptune and Uranus, to say definitely whether or no there does exist an ultra-Neptunian planet capable of giving rise to perturbations in the motion of the planets interior to it. And unless the planet be very distant, quite exceptional in its distance, or considerably smaller than the other giant planets, it must give rise to perturbations in the motion of both Uranus and Neptune. But at present the consideration of the motion of Neptune fails to afford us any answer to our question—Do there exist ultra-Neptunian planets? So there arises the inquiry—Is there any other way in which an answer can be obtained? The reply is—Yes.

It has been found that a large proportion of the known periodical comets are divided into groups in such a manner that in each group, when the comet is at its greatest distance from the sun, or is in aphelion, it lies quite close to the orbit of one of the giant planets. Thus the comets of short period have orbits which are so placed with regard to the orbit of the giant planet Jupiter, and this relationship is so marked that it has led astronomers to suppose that these comets may have been introduced into the solar system by the attraction of this planet. Many of the remaining periodical comets have orbits similarly grouped about those of Uranus and Neptune, as if they had been similarly introduced by those planets. If, then, this view of the mode in which periodical comets are introduced into the solar system be sound, it would be possible to detect other giant planets beyond Neptune by seeing if there exist similar groups of periodical comets.

Considering the periodical comets of long period, many would seem to divide themselves into three groups with aphelion distances of about 45, 75, and 100 times the mean distance of the earth, which on the assumption made would indicate the existence of three ultra-Neptunian planets, with mean distances of about 45, 75, and 100 times that of the earth, and periods of about 300, 650, and 1000 years; and it may be remarked that these distances correspond tolerably well with what from *à priori* reasons might be supposed to be the probable distances of these bodies.

Their discovery.

If such planets really exist, how far is it likely that we should be able to detect them? As they would probably be of about the same dimensions as Uranus and Neptune, they would shine like stars of the tenth, twelfth, and fourteenth standard magnitudes respectively, and their daily heavenly motions would be about 12″, 5″, and 3″ respectively. It is not improbable, sooner or later, if it exists, that the first might be picked up by some astronomer searching for minor planets, or by a comparison of different observations made with the view of mapping the heavens. But the detection of the others would not be possible in this manner, for they are too faint. If they were detected it would only be as the result of a prolonged systematic search with one of the most powerful telescopes. And such a search would be useless unless the actual place of the planet was known with some certainty. At present such a search would be hopeless.

Such planets may exist; and the further progress of astronomy may bring us data by which to determine the probable place of these hypothetical planets, and then a search may lead to the addition of other planets to the solar system. Time will prove.

CHAPTER XIX.

COMETS AND METEORS.

Comets—Periodical—Short Period—Long Period—Extra Solar—Nature of Comets—Spectrum of—Constitution of Comets—Meteors—Meteor Streams—Zodiacal Light.

THESE mysterious bodies, which from time to time sweep rapidly across the heavens, may be divided into two great classes—namely, the periodical comets, which are true members of the solar system, and regularly return at the end of each revolution; and the non-periodical comets, bodies which arriving from distant space sweep round the sun in a parabolic or hyperbolic orbit, and depart again into space to return no more. The former are of course the more interesting to us as being regular members of our system, though from time to time they may be momentarily eclipsed by some exceptionally brilliant or startling visitor from distant realms.

Periodical comets.

The periodical comets may be divided into three classes—namely, comets of short period, comets of moderate period, and comets of long period; and of these the first are perhaps the most interesting, as their more frequent returns enable us to better study their character and investigate their orbits.

The principal members of the family of comets of short period are the following:—

Comets of short period.

1. *Encke's Comet.*—Period 3·300 years; least distance from sun = 0·342; greatest distance from sun = 4·10; last return to perihelion, March 1885; next return, June 1888. This is perhaps the most celebrated of these comets, and has been the one most frequently observed, having been seen on no less than twenty-one of its returns to perihelion, whilst it is the one whose orbit has been most carefully investigated. It had been discovered by Mechain in 1786, by Caroline Herschel in 1795, by Thulis in 1805, and by Pons in 1818, before its real periodical character was discovered. Encke, from the observations made in 1818-19, found that its orbit was unquestionably an ellipse of about 3¼ years period, and by examining a catalogue of the known comets was able to identify it with those seen in 1786, 1795, and 1805. He was consequently enabled to calculate its orbit with exceptional accuracy, and predicted the return of the comet in 1822. The prediction was completely verified, and since then the comet has been seen at all its returns. By a comparison of the time of its theoretical and observed perihelion passage, Encke was led to believe that the comet came back about 2½ hours sooner than it should according to theory, and

that this acceleration was on account of its motion being hindered by some resisting or ethereal medium in space, this resistance tending to diminish the dimensions of the orbit of the comet and so hasten its return to perihelion. At present nothing certain is known on this point, for it is by no means certain that this quickening of the apparent motion of the comet may not be due to some planetary perturbation not properly taken into account. No other comet seems to show the same acceleration unless it be Winnecke's comet, in which a similar but much smaller acceleration has been suspected by Oppolzer. Its amount may be gathered from the statement that whereas the observation of the years 1819 and 1822 seem to indicate a period of 1211·7 days, those at the present time seem to indicate a period of only 1210·0 days. But even if this acceleration be made out, it may not unlikely be due to the near approach of the comet to the sun and its retardation by the outlying portion of the solar atmosphere, or rather the atmospheric envelope to the great meteor streams which seem to surround the sun, and have been suspected to be the real origin of the phenomenon known as the zodiacal light.

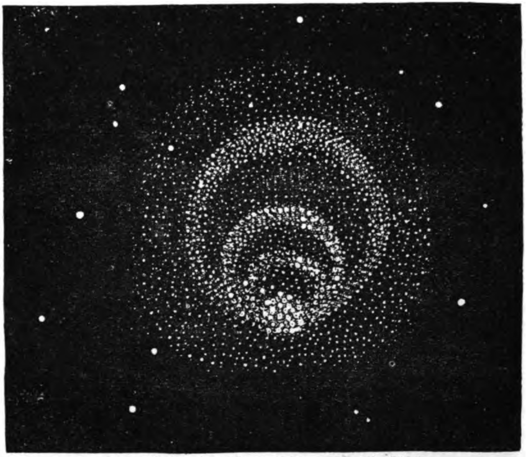


FIG. 66.—ENCKE'S COMET, NOV. 12, 1872.

It may be mentioned here that comets are distinguished by the year of their perihelion passage, and the order in which they pass their perihelion: thus comet 1881 (ii) means the second comet which passed through its perihelion in the year 1881.

2. *Winnecke's Comet.*—Period 5·55 years; least distance from sun =0·78; greatest distance = 5·50; last return, Aug. 1886; next return, March 1892. Discovered by Pons, in June 1819, but not again seen until re-discovered by Winnecke in 1858. Generally small and faint.

3. ***Brorsen's*** *Comet.*—Period 5·56 years; least distance from sun

=0·62; greatest distance = 5·66; last return, Oct. 1885; next return' June 1891. Generally small and faint.

4. *Temple's Comet.*—Period 5·96 years; leastdistance from sun = 1·77; greatest distance = 4·81; last return, April 1885; next return, June 1891, Very faint, resembling in appearance a small rounded nebula. Approached very close to Jupiter in 1882, when the attraction of that planet materially altered its orbit and it was not seen on its return.

5. *D'Arrest's Comet.*—Period 6·39 years; least distance from sun = 1·17; greatest distance = 5·72; last return, Jan. 13th, 1884; next return, June 1890. Discovered by D'Arrest June 27, 1851. Its motion is subject to great perturbations from the attraction of Jupiter. It is small and faint.

6. *Biela's Comet.*—Period 6·62 years; least distance from sun = 1·86; greatest distance = 6·19; last visible return, Sept. 23rd, 1852; next return quite uncertain,—should be Oct. 1892.

This comet was observed in 1772 by Montaigne, and in 1805 by Pons, but it was not until after its discovery in 1826 by Biela that its periodical character was detected. In 1832 and 1846 it was again observed, though found to be faint, and during its return it was seen to gradually separate into two portions which swept along in orbits close to one another. At its return in 1852 the two portions were still distinct, and had separated somewhat further apart. Since that time, though carefully searched for, it has never been found. On Nov. 27th, 1872, and again on Nov. 26th, 1885, the earth swept across the orbit of this comet, and a remarkable display of meteors was observed, but no comet. Similarly it could not be detected in 1879. It seems to have vanished: perhaps become so expanded as to be too faint to be seen.

7. *Faye's Comet.*—Period 7·413 years; least distance from sun = 1·69; greatest distance = 5·92; last return, Dec. 28th, 1880; next return, May 1888. Discovered by Faye on Nov. 22nd, 1843, and has had its orbit carefully investigated by Carl Möller. It has been seen at each return since, and is at times tolerably bright, though not a naked-eye comet. Its motion agrees very closely with theory, and shows no trace of the effect of a resisting medium; but then it does not closely approach the sun.

To these may be added two lately discovered comets of similar period, which have not yet been seen on their return to perihelion.

8. *Swift's Comet.*—Period 5·49 years; least distance from sun = 1·03; greatest distance = 5·00; last visible return, Nov. 6th, 1880; next return, Nov. 1891. Discovered by Swift Oct. 10th, 1880, and found to be identical with a comet discovered by Temple Nov. 27th, 1869. It is tolerably bright, but owing to its proximity to the sun is only to be well seen at every alternate return.

9. *Denning's Comet.*—Period 8·72 years; least distance from sun = ·72; greatest distance = 7·55; last return, Sept. 13th, 1881; next return, April 1890. Discovered by Denning Oct. 4th, 1881. Shown by Winnecke to be moving in an ellipse of short period, and supposed the same as that observed in 1855 by Hind. Tolerably bright.

Belonging to the same group, but of somewhat longer period.

10. *Mechain's Comet.*—Period 13·78 years; least distance from sun

=1·03; greatest distance=10·51; last return, August 1885: next return, June 1899. Discovered by Mechain Jan. 9th, 1790, and rediscovered by Tuttle in 1858. It is faint.

Besides the above comets, 1743 (i.) discovered by Grischau, 1783 (i.) discovered by Pigott, 1819 (iv.) discovered by Blainpain, and 1846 (vi.) discovered by Peters, have been supposed to be comets moving in ellipses with periods of about five years, but have not been again observed. Comet 1770 (i.), called Lexell's comet, has been shown to have had an elliptical orbit of 5½ years period, but its orbit lay so close to the planet Jupiter that the attraction of that body seems to have completely changed its orbit, so that though a bright comet it has never been again seen.

Nearly all the comets of this group (that is, of short period) are telescopic comets—that is, too faint to be seen without telescopic aid except under favourable opportunities. Encke's comet can be distinctly seen with the naked eye.

The comets of moderate period are some eight in number, most of them having orbits of about seventy years period, and with their aphelion distance close to the orbit of Neptune. They are—

Pechyle's, 1866 (i.).	Period	53·0	Next return about	1919
Hartwig's, 1880 (iv.)	,,	62·3	,, ,,	1942
Westphal's, 1852 (iv.)	,,	67·8	,, ,,	1920
Pons', 1812 (i.)	,,	70·7	,, ,,	1954
Di Vico's, 1846 (iv.)	,,	73·2	,, ,,	1919
Olbers', 1815 (i.)	,,	74·0	,, ,,	1888
Brorsen's, 1847 (v.)	,,	75·0	,, ,,	1922
Halley's	,,	76·8	,, ,,	1912

Of these the only one of any exceptional interest is Halley's. Most of the others are faint comets, though brighter than those of shorter period, and almost all were distinctly visible to the naked eye. Halley's comet, at some of its apparitions, has been exceptionally brilliant. The next brightest seem to be Hartwig's and Pons' comets. This last was seen on its second return in 1884 as a fairly bright comet.

Halley's Comet.—Period 76·00 years; least distance from sun=0·59; greatest distance=35·30; last return, Nov. 15th, 1835; next return, 1912.

Halley's comet is famous as being the first whose periodical character was detected and whose return was duly predicted. The circumstances regarding the detection of its periodicity by Halley, whilst engaged on the study of the great comet of 1682, have been already mentioned. Owing to the investigations of Hind seventeen apparitions of this fine comet have been identified, and there can be little doubt that some of the most remarkable apparitions recorded are returns of Halley's comet. Thus the magnificent comet seen in 1066, and considered by contemporary historians as the prediction of the Norman Conquest, and the great comet of 1456, the precursor of the Wars of the Roses, were apparitions of this comet.

The group of comets of long period do not require special consideration, for their exact periods and orbits are very imperfectly known, and few of them seem especially remarkable. They are about twenty-five in number, and have periods of from one hundred to some five hundred years. These comets are only visible when in the very small portion of their orbit which lies near to the sun and earth, so that very trifling errors made in observing their position, when in this small portion of their orbits, cause very large errors in the determination of their exact orbits. And from their ill-defined character it is not easy to determine accurately the exact place of a comet. The most remarkable comets of this group are, perhaps, the magnificent comets 1843 (i.) and 1861 (ii.), each of which is supposed to move in an orbit with a period of about 400 years.

Comets of long period.

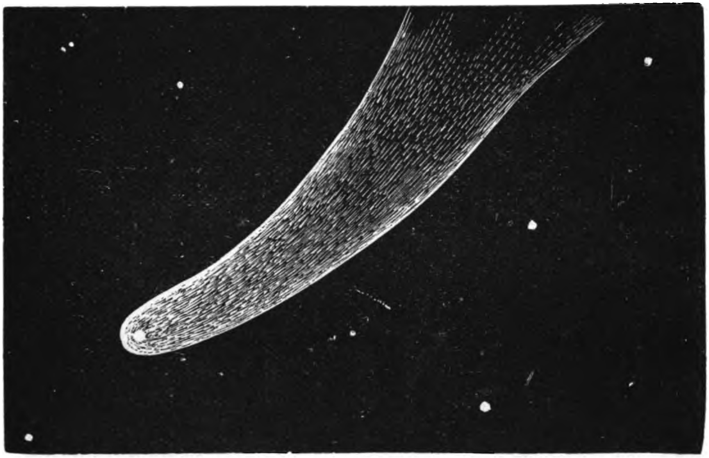


FIG. 67.—GREAT COMET OF 1811.

Some of the finest comets, however, which have been seen, are probably mere visitors to the solar system, moving in either parabolic orbits or in elliptic orbits of such immense dimensions that, before reaching their aphelion, they come under the influence of the attraction of some other sun and so return no more. The principal of these comets seem to have been the following :—

Extra-solar comets.

1264. (i.) An exceedingly brilliant comet, visible during the whole summer, and having a tail stretching right across the heavens.

1472. (i.) A brilliant comet which was visible during most of the winter. It came very close to the earth, and possessed a long broad tail. During the middle of January it was said to have been conspicuous even during the day.

1618. (iii.) A celebrated comet visible for over a month during the middle of the winter. It was noteworthy from its great brilliancy and fine tail, which was said to be decidedly reddish in tinge. When at its finest it had a tail over 100° in length, and the nucleus was distinctly seen in broad sunlight. It was the first great comet seen through a telescope.

1680. (i.) Conspicuous throughout the entire winter, as a brilliant comet, with a long bright tail. It has been thought to be a comet of comparatively short period.

1744. (i.) This was the finest comet of modern times, and was visible during the entire winter and early spring. It had a bright nucleus and a widely forked tail; indeed, Cheseaux ascribes to it no less than six tails at one time, probably minor divisions of the principal one.

1769. (i.) Visible during the spring. A conspicuous object with a long curved tail.

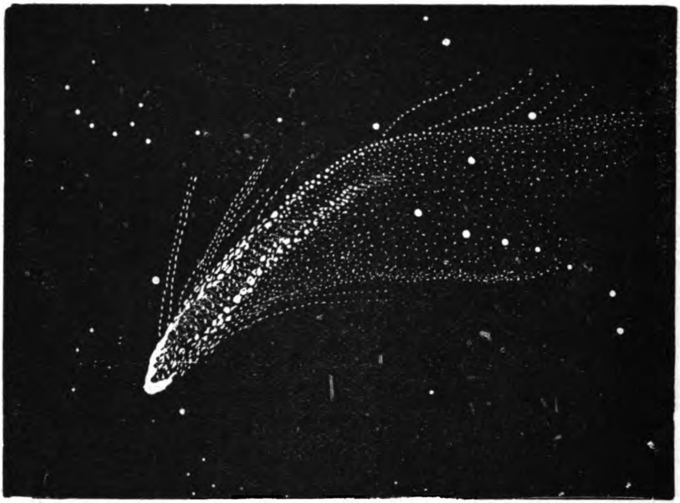


FIG. 68.—DONATI'S COMET, 1858.

1811. (i.) One of the most celebrated on record, and remained visible for considerably over a year, being very conspicuous in the northern heavens during the autumn of 1811. It had a very brilliant nucleus, and a long broad tail, with bright edges and a fainter interior. A figure of this comet has already been given.

1843. (i.) An exceedingly brilliant comet, with a very long tail, which became suddenly visible in the southern hemisphere in February, 1843. It is noteworthy for its very close approach to the sun, at its perihelion being distant scarcely a quarter of a million miles from the surface of the sun.

1858. (vi.) Donati's comet. One the finest of this century. It was discovered on June 2nd, near λ Leonis, as a faint nebulous object, being then nearly 240,000,000 miles' distance from the earth; but it slowly became brighter, and during the early autumn of 1858 formed a very conspicuous object, with a brilliant nucleus and a fine broad tail.

1861. (ii.) This great comet was discovered in Australia in May, but did not become visible in England till June 29th, when its brilliant tail rising above the horizon attracted general attention. It rapidly faded away, however. It is considered very probable that on Sunday, June 20th, the earth passed through the extremity of the tail of this comet, and it is noteworthy that a very peculiar phosphorescent haze was observed during the day.

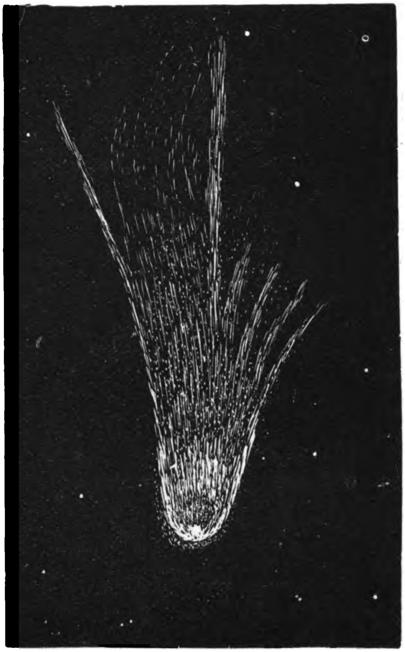


FIG. 69.--COMET OF JULY 1861.

1880. (i.) This was a remarkable comet, only seen in the southern hemisphere, but bearing a considerable resemblance in its character and orbit to the famous comet of 1843. It approached exceedingly close to the sun at its perihelion passage, and rapidly grew fainter after its discovery. It has been thought to be identical with the comet of 1843 (i.), and perhaps with one of the very similar comets which appeared in 1695 and 1689. If so, its orbit must be rapidly decreasing; and it has been supposed that the comet may in consequence reappear in 1897 and fall into the sun.

1882. (ii.) A very fine comet, with enormous slightly curved tail, crossing the disc of the sun on September 17th, but though visible right up to the time of entering the disc, could not be seen in transit. Visible for some months. Moves in a very similar orbit to those of the southern comets of 1843 and 1880.

Nature of comets.

What is the true nature of these comets? That is a question which has never yet been satisfactorily answered. It seems certain that there is some close connection between comets and meteors; for close examination has shown that the paths of a number of the most brilliant meteor streams are coincident with orbits of known comets.

Thus the great meteoric displays of November, which occur about every thirty-three years, are due to a grand stream of meteors moving in the same orbit as the comet 1866 (i.), and are coincident in their epoch of maximum splendour with the reappearance of the comet. Thus the comet passed its perihelion in 1799, 1833, and 1866, and the following Novembers were the times of the great displays of these meteors. Similarly the brilliant displays of meteors in August are found to be due to a meteor stream moving in the same path as the comet 1862 (ii.). The question arises, then, Are comets only the nuclei of great meteor streams? and are the tails of comets only the denser portion of the meteor stream? This appears improbable, for we know two or three comets whose orbits intersect that of the earth, but which are not associated with any great meteoric displays. Yet it seems certain that there is some connection.

Comets and meteors.

pectrum of comets.

When comets are examined with the spectroscope, they yield a spectrum of bright bands which seem coincident with the spectrum of incandescent gaseous hydrocarbons. Other bands have at times been suspected which would indicate the existence of nitrogen. Are these comets masses of incandescent gases? This seems inconsistent with physical laws, for it does not seem conceivable that these masses of gas should retain their high temperature and avoid being condensed by the effects of gravitation.

Probable nature of comets.

What, then, is the probable constitution of comets? The most probable hypothesis seems to be that which regards comets to be composed of great masses of highly rarefied gases surrounding a mass of meteors. The attraction of the meteors upon their surrounding gaseous envelope prevents the mass of gas either condensing towards a central nucleus, or rarefying away into space, whilst the mutual action and reaction of the meteors upon themselves and upon their gaseous envelope tends to keep the comet together. In the nucleus these meteors would be more closely packed and in the tail less closely packed. When examined with the spectroscope, these meteoric bodies being so small —perhaps the largest not many yards in diameter—would reflect or emit so little light that they would escape detection, and only the spectrum of the surrounding gaseous envelope be detected. And the high temperature? It is not certain that these comets really have a high temperature. As will be seen when the nature of nebulæ comes to be discussed, large volumes of gas at even low temperatures may emit sufficient light to yield a spectrum. But as the comets approach the sun it is certain that the meteors will gradually close up and approach very much nearer to each other than in other parts of their orbits, and this approach must lead to a considerable condensation of their gaseous envelopes, and so tend to raise the temperature of the comet very considerably. The hypothesis which is here sketched seems to afford the most probable theory of the constitution of the comets, it being one which, when fully worked out—which cannot be done here—will be found to explain the greater number of the phenomena presented by comets; and, when more elaborately treated, may not unlikely be found capable of explaining all.

The meteor streams which accompany many comets would then be

Disintegrated comets.

the results of the disintegration of a comet, for as the meteors became dispersed so would the gaseous envelope, and in course of time there would no longer exist a sufficiently compact mass of meteors to form a comet. Thus the lost Biela comet seems to have completely disintegrated into meteoric masses. We should naturally expect to find, therefore, not only meteor streams without comets—which is very common—but comets which, owing to their being but little disintegrated, were without conspicuous meteor streams.

Meteors. The last division of the members of the solar system are the meteors, and meteor streams.

Meteor streams.

It has been supposed that the entire solar system is traversed by innumerable streams of meteors, mostly exceedingly small in size, probably ranging in dimensions from the size of peas to about that of a cricket-ball, though some few may reach much larger dimensions, as occasionally falls are recorded of meteors of nearly a ton in weight. The number of these small bodies which cross the earth's orbit must be enormous, for it has been calculated that seven million meteors enter the earth's atmosphere every twenty-four hours, which would correspond to between two and three thousand millions per year. Yet the earth cannot encounter more than one meteor stream for each of the many million whose orbit must pass above or below the place of the terrestrial orbit. But despite these enormous numbers it is calculated that the average number of meteors is less than one per million cubic miles of space, so that, if they were equally distributed, the mean distance between each meteor would be over one hundred miles. But, as stated, these meteors seem to move in streams, and in these streams the meteors are probably much closer together—perhaps in the greater streams not more than two or three miles apart, or even closer. The relationship between the comets and these meteor streams has been already discussed.

Enormous number.

Zodiacal light.

When the western sky is observed during the winter or early spring, just after sunset, a lens-shaped stream of faint diffused light will frequently be noticed rising obliquely from the horizon above the place where the sun has set. It rises in a direction showing it to be nearly coincident with the ecliptic, and much resembles in appearance the belt of light called the *Milky Way*. This band of faint light is called the *zodiacal light*. During the autumn months it can generally be seen before sunrise, extending above the eastern horizon, showing it to exist on both sides of the sun. The exact origin of this band of faint light is not known; but it seems probable that it is due to the great number of meteors moving round the sun, as these streams would reflect the solar light in a manner very analogous to what we find in the zodiacal light. Its convex lens-like shape conveying the idea of a broad ring of light surrounding the sun, strongly confirms this. We know that near the sun the numerous meteor streams moving round this body must be much more closely packed than when farther away, and their proximity to the sun must make them shine much more brightly, so we should naturally expect some such phenomenon to exist.

Its origin.

Indeed, the theory of the constitution of comets, which has been already described, would naturally lead to this conclusion, and would explain the resemblance which has been noted between the zodiacal light and the tails of comets by showing them to be of the same origin.

CHAPTER XX.

ULTRA-SOLARIAN ASTRONOMY.

Stars--Magnitude—Visibility—Number—Nomenclature.

HITHERTO we have dealt with the astronomy of the solar system, or at least with bodies coming within the confines of the solar system. Now we have to consider the astronomy of the remainder of the universe, as revealed by the stars, especially by the binary double stars and the nebulæ.

The first to be dealt with will be the stars, and particularly the double stars.

Stars visible to the naked eye.

The total number of stars which can be ordinarily seen with the naked eye on a bright clear night is about two thousand in number, and the greater part of these are very faint. The actual number of stars which readily catch the eye on a bright, starlight night, do not amount to over six hundred. And yet, when one surveys the heavens, the stars seem far too numerous to be numbered. As at any time only one-half of the entire heavens can be seen, it follows that the total number of stars that can be seen with unaided vision must be some four thousand in number—they are really nearly five thousand in number—but then the fainter stars, which lie near the horizon at any moment, cannot be seen with the naked eye, though they would be distinct enough if sufficiently far above the horizon to escape the dimming effects of the thin haze and cloud which always exist there.

Star magnitude.

It has been already mentioned that astronomers divide the stars into different magnitudes, those of the first magnitude being the brightest, those of the second magnitude the next brightest, while those of the sixth magnitude are the faintest visible to the naked eye. But astronomers do not stop here, and the still fainter stars, only visible in a telescope, are similarly divided into stars of the seventh, eighth, ninth, and so on, magnitudes. Then the stars of each magnitude are subdivided into tenths of a magnitude, and so on. Thus stars of the 5th magnitude comprise all stars which are fainter than the 4·5 magnitude, but brighter than 5·5 magnitude.

It must be remarked, though, that some astronomers, instead of dividing stars into tenths of a magnitude, do so into only thirds, and in this manner: 4-5 or 5-4 ; by which they mean in the first case a star not so bright as a 4th, but not near so faint as a 5th, or about a $4\frac{1}{3}$rd : whilst in the second case is meant a star brighter than the 5th, but not near so bright as a 4th, or a $4\frac{2}{3}$rds. Sometimes the hyphen is replaced by a dot, or they are written 4.5 and 5.4, and it is then necessary to be careful not to confuse with a star of the 4·5 or 4½ magnitude.

According to the standard scale of magnitudes, a star of any given magnitude—say the 5th—is 2½ times as bright, or sends to us 2½ times as much light, as a star of one magnitude less—say the 6th magnitude. And here it may be remarked that astronomers usually term a 6th magnitude star one of *less* magnitude than a 5th magnitude, and a 7th magnitude as of less magnitude than a 6th magnitude star, and so on, whilst a star of the 4th magnitude would be said to be of *greater* magnitude; but on the other hand, they commonly refer to stars of the 6th and 7th magnitudes as being stars of *higher* magnitudes than those of the 5th. Then, taking a star of the 6th magnitude to be of unit brightness, the brightness of the stars of other magnitudes will be :—

Difference in light.

1st mag. = 100
2nd " = 40
3rd " = 16
4th " – 6¼
5th " = 2½
6th " = 1

7th mag. = 2/5
8th " = 1/6
9th " = 1/16
10th " = 1/40
11th " = 1/100
12th " = 1/250.

These refer to *standard* magnitudes, so called because they are reckoned on the scale which is gradually being introduced and accepted as a standard amongst astronomers. It is practically coincident with the scale used by Argelander in his great survey of the heavens. But there are other scales of magnitude in common use, which somewhat differ from these. Up to stars of the 9th magnitude these differences are not important, and all scales may be considered as very much alike; but for very faint telescopic stars some of the scales differ very materially. The principal of these scales may be said to be one adopted more or less uniformly by Herschel, Smyth, and Webb, and commonly called Smyth's scale and denoted by Sm.; the other is one used by Struve, and in a slightly amended form by his son Otto Struve; it is commonly denoted by Σ, a capital Greek Sigma. Both these scales are generally restricted to the companions of double stars. The following give an approximate comparison between these scales and the standard one :—

Different scales.

Standard Scale.	Smyth's Scale.	Struve's Scale.	Aperture.
10	10	9½	1½
10½	11	9⅚	2
11	12	10⅓	2½
11½	13	10¾	3¼
12	14	11⅓	4
12½	15	11¾	5
13	16	12⅓	6½
13½	17	12⅔	8
14	18	13⅓	10
14½	19	13⅔	13
15	20	14¼	16

Under the heading "aperture," there is given the smallest telescopic aperture which will, under ordinary conditions, show a star of the given magnitude. Thus in a telescope of 6½ inches aperture, as a general rule, no star will be visible which is less bright than a star of the 13th standard magnitude, or, what is the same thing, of the 16th magnitude according to Smyth. Under exceptionally favourable circumstances, or to exceptionally keen-eyed observers, it may just show a star of half a magnitude smaller, say 13½ magnitude; but, on the other hand, as a rule no star of smaller magnitude than the 12½ will be visible unless carefully looked for.

Stars visible in different telescopes.

All the stars in the northern hemisphere down to 9½ magnitude have been observed and mapped by Argelander; and the numbers are as follows:—

Number of stars.

10	stars between	1·0	mag. and	1·9	mag.
37	„	2·0	„	2·9	„
128	„	3·0	„	3·9	„
310	„	4·0	„	4·9	„
1016	„	5·0	„	5·9	„
4328	„	6·0	„	6·9	„
13593	„	7·0	„	7·9	„
57960	„	8·0	„	8·9	„
237544	„	9·0	„	9·5	„

And it has been calculated that there are in the entire heavens over two and a half million stars brighter than the 10th magnitude. So that though with the naked eye only some 5000 stars can be seen, yet with the aid of the smallest telescope, little more powerful than an opera-glass, over 2,500,000 stars can be seen.

These stars are divided into constellations according to very ancient usage; the boundaries of these constellations being very vague. The brighter stars in these constellations are distinguished by the Greek letters α, β, γ. . . . Others, less important, are distinguished by English letters *a*, *b*, *c*, or by numbers, principally the numbers in Flamstead's catalogue of the stars. Others, again, are distinguished by the number they bear in other catalogues—as the great catalogue of the British Association, abbreviated into B.A.C. Amongst double stars the principal abbreviations are Σ for Struve's catalogue, and O Σ for Otto Struve's catalogue, and H for Herschel's catalogue. P, with Roman figures showing the hour of R.A., stands for Piazzi's catalogue. The position of the stars in these constellations, and the position of the constellations themselves, can only be learned by comparing a good star atlas with the heavens, Proctor's star atlas being the best for this purpose.

Nomenclature.

CHAPTER XXI.

DOUBLE STARS.

Division of Double Stars — Appearance — Catalogue of Selected Doubles — Binary Doubles.

A VERY great number of double stars are now known, a number perhaps merely optically double; but, on the other hand, a great number are true double stars, or systems of bodies moving round their common centre of gravity.

The observation of these double stars forms one of the more interesting branches of telescopic work, and is one which possesses peculiar fascination for most amateur observers. It is indeed one well within their reach, for it only requires the possession of a good equatorial telescope.

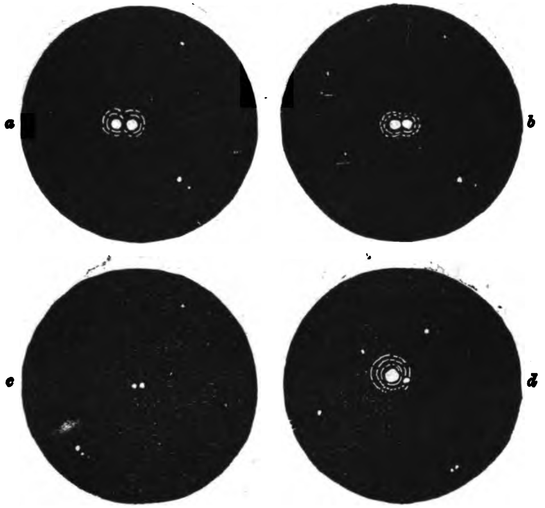


FIG. 70.
a, Double star, separated; *b*, Double star, not quite separated; *c*, Small double stars; *d*, Unequal double star, with faint companion.

Division of double stars.

Double stars afford also very good tests of the quality of a telescope. A telescope of good quality ought to be able to separate, or divide as it is called, a double star whose nearly equal components of about the sixth magnitude are not more than 4·5″÷ (aperture of telescope in inches) apart: that is to say, should show the two stars as perfectly separated from each other, and visible as being rounded discs, as in fig. 70. If the star is only elongated, as in the next figure, it is not said to be separated or

Appearance of double stars.

divided. On the other hand, if the stars are small—say of the eighth or ninth magnitude—they will be shown, as in the third figure, without diffraction rings round them; or, if the brighter star be of the third or fourth magnitude, and the smaller star of about the eighth or ninth, it will be visible something like in the fourth figure. A single moderately bright star should appear quite circular, and surrounded by delicate diffraction rings, as in *e* of fig. 71.

Over ten thousand double stars are now known, and many others are being discovered every year. The greater number of these are of slight importance; but some few are of exceptional interest. The following list contains a selection of these double stars. There is given first the name of the star, then its R.A. and Dec., a + showing north declination, and a – south declination. Next follows the standard magnitude of the stars, then their position angle and distance; the position angle being measured from the brighter star in the way described in page 78. Lastly there is given the colours of the two stars.

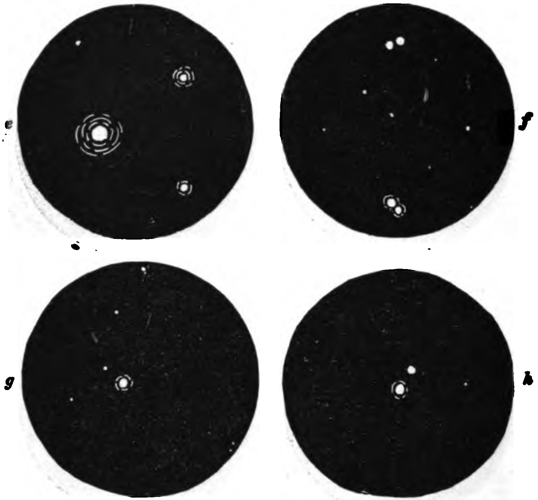


FIG. 71.
e, Single stars of different magnitudes; *f*, ε Lyræ; *g*, ζ Persei; *h*, ε Hydræ.

Catalogue of stars.

η *Cassiopeiæ.*—R.A. = $0^h\ 42^m$. Dec. = + 57° 11′. Mag. 4 and 7½. Pos. ang. 160°. Dist. 5″. White and reddish-white. A binary star.

μ *Andromedæ.*—R.A. = $0^h\ 50^m$. Dec. = + 37° 51′. Mag. 4 and 13. Pos. ang. 115°. Dist. 45″. White and grey. A good test for the delicacy of the eye.

α *Ursæ Minoris.*—R.A. = $1^h\ 15^m$. Dec. = + 88° 40′. Mag. 2·5 and 9. Pos. ang. 210°. Dist. 19″. Yellow and white.

γ *Aries.*—R.A. = 1^h 47^m. Dec. = + 18° 42′. Mag. 4½ and 5. Pos. ang. 358°. Dist. 8·8″. White.

ε *Triangulum.*—R.A. = 1^h 56^m. Dec. = + 32° 42′. Mag. 5½ and 12½. Pos. ang. 110°. Dist. 5″. Yellowish-white.

α *Pisces.*—R.A. = 1^h 56^m. Dec. = + 20° 11′. Mag. 5 and 6. Pos. ang. 326°. Dist. 3·1″. Bluish-white and yellowish-white. Colours thought to be variable.

γ *Andromeda.*—R.A. = 1^h 57^m. Dec. = + 41° 45′. Mag. 3½ and 5½. Pos. ang. 62°. Dist. 10″. Deep-yellow and green. The smaller star is in turn double, but very close. Pos. ang. 98°. Dist. 0·4″. Colours green and blue. A binary, and now closing up. Test for large apertures.

ι *Triangulum.*—R.A. = 2^h 5^m. Dec. = + 29° 44′. Mag. 5½ and 7. Pos. ang. 79°. Dist. 3·5″. Topaz yellow and bluish-green.

ν *Ceti.*—R.A. = 2^h 30^m. Dec. = + 5° 3′. Mag. 4½ and 12. Pos. ang. 85°. Dist. 6″. Yellow, blue; companion perhaps variable.

γ *Ceti.*—R.A. = 2^h 37^m. Dec. = + 2° 44′. Mag. 3 and 7. Pos. ang. 286°. Dist. 2·6″.

π *Arietis.*—R.A. = 2^h 43^m. Dec. = + 16° 58′. Mag. 5, 8½, and 11½. Pos. ang. 122° and 110°. Dist. 3·1″ and 25″. Smaller companion perhaps variable.

ε *Arietis.*—R.A. = 2^h 52^m. Dec. = + 20° 52′. Mag. 5 and 6½. Pos. ang. 204°. Dist. 1·4″. White. Probably a binary. Certainly becoming rapidly wider.

52 *Arietis.*—R.A. = 2^h 58^m. Dec. = + 24° 47′. Mag. 6½, 7, 12, 12. Pos. ang. 269°, 355°, and 85°. Dist. 0·8″, 5″, and 105″. White, blue, blue, and lilac. A quadruple star. The two closer form probably a binary pair.

94 *Ceti.*—R.A. = 3^h 7^m. Dec. = – 1° 39′. Mag. 5½ and 13½. Pos. ang. 260°. Dist. 5″. White, bluish. A very delicate test; not easy even in large telescopes.

30 *Tauri.*—R.A. = 3^h 42^m. Dec. = + 10° 46′. Mag. 6 and 10. Pos. ang. 59°. Dist. 9″. Pale emerald and purplish.

ζ *Persei.*—R.A. = 3^h 47^m. Dec. = + 31° 32′. Mag. 3½, 10½, 12, 11, 10½. Pos. ang. 207°, 290°, 198°, 185°. Dist. 13″, 34″, 90″, 121″. White, small comites, blue.

o^2 *Eridani.*—R.A. = 4^h 10^m. Dec. = – 7° 50′. Mag. 5 and 9½. Pos. ang. 107°. Dist. 84″. Orange and blue. Companion double, 9·5 and 10·8. Pos. ang. 118°. Dist. 3·2″. Probably a binary double. The whole system is rapidly moving in the heavens.

80 *Tauri.*—R.A. = 4^h 23^m. Dec. = + 15° 23′. Mag. 6 and 8½. Pos. ang. 5°. Dist. 0·6″. Yellowish.

ι *Leporis.*—R.A. = 5^h 7^m. Dec. = – 12° 1′. Mag. 4½ and 11. Pos. ang. 337°. Dist. 15″. White and violet.

ρ *Orionis.*—R.A. = 5^h 7^m. Dec. = + 2° 43′. Mag. 5 and 10. Pos. ang 62°. Dist. 6·8″. Orange and pale blue.

κ *Leporis.*—R.A. = 5^h 8^m. Dec. = – 13° 5′. Mag. 5 and 9. Pos. ang. 0°·0. Dist. 3·7″. White.

β *Orionis.*—R.A. = 5^h 9^m. Dec. = – 8° 20′. Mag. 1 and 8. Pos. ang. 200°. Dist. 9·5″. Yellow and blue. Companion itself a very close double.

η *Orionis.*—R.A. = 5^h 18^m. Dec. = – 2° 3′. Mag. 4 and 5. Pos. ang. 78°. Dist. 0·9″. White. A capital test.

ψ^2 *Orionis.*—R.A. = $5^h\ 21^m$. Dec. = + 2° 59′. Mag. 5½ and 11½. Pos. ang. 322°. Dist. 2·8″.

33 *Orionis.*—R.A. = $5^h\ 25^m$. Dec. = + 3° 12′. Mag. 6 and 8. Pos. ang. 26°. Dist. 2″.

γ *Orionis.*—R.A. = $5^h\ 29^m$. Dec. = + 9° 51′. Mag. 4, 6, 12. Pos. ang. 43° and 183°. Dist. 4·5″ and 29″ Yellow, blue, blue. Triple.

ζ *Orionis.*—R.A. = $5^h\ 35^m$. Dec. = − 2° 0′. Mag. 2·8, 6½, 10. Pos. ang. 149° and 8°. Dist. 2·5″ and 56″. Yellow, blue, blue.

52 *Orionis.*—R.A. = $5^h\ 42^m$. Dec. = + 6° 25′. Mag. 6 and 6½. Pos. ang. 200°. Dist. 1·8″.

4 *Monoceros.*—R.A. = $6^h\ 3^m$. Dec. = − 11° 8′. Mag. 6, 11, and 12. Pos. ang. 179° and 244°. Dist. 3·4″ and 10″. Yellow, blue, blue.

μ *Geminorum.*—R.A. = $6^h\ 16^m$. Dec. = + 22° 34′. Mag. 3, 12. Pos. ang. 76°. Dist. 73″. Yellow and blue. Fine contrast in hue.

12 *Lyncis.*—R.A. = $6^h\ 36^m$. Dec. = + 59° 34′. Mag. 6, 6½, and 7½. Pos. ang. 128° and 305°. Dist. 1·4″ and 8″. White, reddish, and bluish. Fine triple.

α *Geminorum.*—R.A. = $7^h\ 27^m$. Dec. = + 32° 9′. Mag. 3 and 3½. Pos. ang. 235°. Dist. 5·6″. White. A splendid pair, though wide.

κ *Geminorum.*—R.A. = $7^h\ 37^m$. Dec. = + 24° 41′. Mag. 4 and 10. Pos. ang. 232°. Dist. 6″. Orange and blue. The companion has been supposed very variable.

6 *Cancri.*—R.A. = $7^h\ 56^m$. Dec. = + 28° 8′. Mag. 5, 12½, 13. Pos. ang. 70° and 180°. Dist. 70″ and 65″.

ξ *Cancri.*—R.A. = $8^h\ 5^m$. Dec. = + 18° 1′. Mag. 6, 7, and 7½. Pos. ang. 90° and 130°. Dist. 0·8″ and 5·6″. Yellowish-white. All these form part of one system.

ϕ^2 *Cancri.*—R.A. = $8^h\ 20^m$. Dec. = + 27° 20′. Mag. 6·4 and 6·6. Pos. ang. 214°. Dist. 4·8″. White.

ε *Hydræ.*—R.A. = $8^h\ 40^m$. Dec. = + 6° 51′. Mag. 4, 8½, and 14½. Pos. ang. 220° and 192°. Dist. 3·5″ and 20·5″. White, purple, blue. The minute companion very difficult.

σ^2 *Cancri.*—R.A. = $8^h\ 47^m$. Dec. = + 31° 2′. Mag. 6 and 6½. Pos. ang. 335°. Dist. 1·4″. Yellow.

ι *Ursæ Majoris.*—R.A. = $8^h\ 51^m$. Dec. = + 48° 31′. Mag. 3½ and 12. Pos. ang. 357°. Dist. 9·8″. Yellow and purple.

σ^2 *Ursæ Majoris.*—R.A. = $9^h\ 0^m$. Dec. = + 67° 37′. Mag. 5½ and 10. Pos. ang. 244°. Dist. 2·5″. White and blue.

θ *Hydræ.*—R.A. = $9^h\ 8^m$. Dec. = + 2° 47′. Mag. 4½ and 11. Pos. ang. 168°. Dist. 45″. Yellow.

38 *Lyncis.*—R.A. = $9^h\ 11^m$. Dec. = + 37° 19′. Mag. 4 and 7½. Pos. ang. 242°. Dist. 2·8″. White.

γ *Leonis.*—R.A. = $10^h\ 13^m$. Dec. = + 20° 27′. Mag. 2 and 3½. Pos. ang. 113°. Dist. 3·4″. Yellow.

49 *Leonis.*—R.A. = $10^h\ 29^m$. Dec. = + 9° 16′. Mag. 6 and 9. Pos. ang. 158°. Dist. 2·5″. White and blue.

ξ *Ursæ Majoris.*—R.A. = $11^h\ 12^m$. Dec. = + 32° 13′. Mag. 4 and 5. Pos. ang. 280°. Dist. 1·8″. White.

ν *Ursæ Majoris.*—R.A. = $11^h\ 12^m$. Dec. = + 33° 45′. Mag. 4 and 11. Pos. ang. 147°. Dist. 7·8″. Orange and blue. Good test for moderate apertures.

ι *Leonis.*—R.A. = 11^h 18^m. Dec. = + 11° 12′. Mag. 4 and 7½. Pos. ang. 69°. Dist. 2·9″. Yellow and pale blue.

2 *Coma Berenicis.*—R.A. = 11^h 58^m. Dec. = + 22° 8′. Mag. 6 and 7½. Pos. ang. 240°. Dist. 3·6″. White and bluish.

γ *Virginis.*—R.A. = 12^h 36^m. Dec. = − 0° 47′. Mag. 4 and 4. Pos. ang. 156°. Dist. 5·0″. White, yellowish-white. A beautiful binary pair, which have been widening since they closed up in 1836.

35 *Coma Berenicis.*—R.A. = 12^h 47^m. Dec. = + 21° 54′. Mag. 5, 8, 9½. Pos. ang. 63° and 127°. Dist. 1·3″ and 29″. Yellowish, purplish, and blue.

ζ *Ursæ Majoris.*—R.A. = 13^h 19^m. Dec. = + 55° 33′. Mag. 2½ and 4½. Pos. ang. 147°. Dist. 14·4″. White and pale green. Has been photographed by Bond.

π *Bootis.*—R.A. = 14^h 35^m. Dec. = + 16° 56′. Mag. 4 and 6. Pos. ang. 101°. Dist. 6″.

ζ *Bootis.*—R.A. = 14^h 35^m. Dec. = + 14° 15′. Mag. 3½ and 4. Pos. ang. 299°. Dist. 1·0″.

ε *Bootis.*—R.A. = 14^h 40^m. Dec. = + 27° 35′. Mag, 3 and 6½. Pos. ang. 325°. Dist. 3·1″. Orange and greenish-blue. It is easier with small apertures than with 5 to 6 inches.

η *Coronæ Borealis.*—R.A. = 15^h 18^m. Dec. = + 30° 43′. Mag. 5½ and 6. Pos. ang. about 120°. Dist. 0·4″. A rapidly revolving binary pair, about now at their closest.

μ *Bootis.*—R.A, = 15^h 20^m, Dec. = + 37° 47′. Mag, 4 and 8. Pos. ang. 172°. Dist. 109″. Yellow and greenish-white. The companion is the famous double μ^2 Bootis. Mag. 8·2 and 8·6. Pos. ang. 120°. Dist. 0·8″. Probably all members of one system.

δ *Serpentis.*—R.A. = 15^h 29^m. Dec. = + 10° 56′. Mag. 3 and 4½. Pos. ang. 188°. Dist. 3·6″. White and bluish-white.

α *Serpentis.*—R.A. =15^h 31^m. Dec. = + 6° 48′. Mag, 2½ and 11½. Pos. ang. 354° Dist. 59″.

β *Scorpii.*—R.A. = 15^h 58^m. Dec. = − 19° 29′. Mag. 2, 10, 5½. Pos. ang. 87° and 25°. Dist. 0·7″ and 13″. A splendid test in good air.

σ *Coronæ Borealis.*—R.A. = 16^h 10^m. Dec. = + 34° 10′. Mag. 6 and 6½. Pos. ang. 206°. Dist. 3·5″. White and bluish-white. A well-known binary.

α *Scorpii.*—R.A. = 16^h 22^m. Dec. = + 26° 10′. Mag. 1 and 7. Pos. ang. 276°. Dist. 3·7″. Red and vivid green. A splendid pair under good atmospheric condition.

λ *Ophiuchi.*—R.A. = 16^h 25^m. Dec. = + 2° 15′. Mag. 4 and 6. Pos. ang. 39°. Dist, 1·7″. Yellow.

ζ *Herculis.*—R.A. = 16^h 37^m. Dec. = + 31° 49. Mag. 3 and 6½. Pos. ang. 105°. Dist. 1·4″. Yellow. Binary pair. Period about 35 years.

μ *Draconis.*—R.A. = 17^h 3^m. Dec. = + 54° 38′. Mag. 4½ and 5. Pos. ang. 167°. Dist. 2·4″. Binary.

α *Herculis.*—R.A. = 17^h 9^m. Dec. = + 14° 32′. Mag. 3 and 6. Pos. ang. 118°. Dist. 4·7″. Orange and green.

ρ *Herculis.*—R.A. = 17^h 20^m. Dec. = + 37° 15′. Mag. 4 and 5½. Pos. ang. 308°. Dist. 3·7″. Bluish-white and fine green.

μ *Herculis.*—R.A. = 17^h 42^m. Dec. = + 27° 48′. Mag. 4 and 10. Pos. ang. 242°. Dist. 30″. Yellow and blue. Companion a rapidly moving binary. Mag. 10½ and 11. Pos. ang. 255°. Dist. 0·9″.

70 *Ophiuchi.*—R.A. = 17^h 59^m. Dec. = + 2° 32′. Mag. 4½ and 7. Pos. ang. 65°. Dist. 2·9″. Binary. Period of 80 years.

α *Lyræ.*—R.A. = 18^h 33^m. Dec. = + 38° 40′. Mag. 0·8 and 10½ Pos. ang. 150°. Dist. 46″. White and blue.

ε *Lyræ.*—R.A. = 18^h 40^m. Dec. = + 39° 33′. A double double, separated by about 200″. Mag. 5 and 6½. Pos. ang. 20°. Dist. 3·0″. Mag. 5 and 5½. Pos. ang. 148°. Dist. 2·5″. Between the two are a 9 mag. star and two 11½ mag. stars. Some 12 and 13 mag. stars lie near them.

17 *Lyræ.*—R.A. 19^h 3^m. Dec. = + 32° 19′. Mag. 6 and 10½. Pos. ang. 322°. Dist. 3·6″. Yellow and blue.

β *Cygni.*—R.A. = 19^h 41^m. Dec. = + 27° 42. Mag. 3 and 6. Pos. ang. 56°. Dist. 3·4″. Golden yellow and blue.

δ *Cygni.*—R.A. = 19^h 41^m. Dec. = + 44° 50′. Mag. 3 and 8. Pos. ang. 320°. Dist. 1·5″. Yellow and bluish-green. Fine test. Is a binary with period of some 200 years.

π *Aquila.*—R.A. = 19^h 43^m. Dec. = + 11° 31′. Mag. 6 and 7. Pos. ang. 121°. Dist. 1·5″. White.

o^2 *Cygni.*—R.A. = 20^h 10^m. Dec. = + 46° 23′. Mag. 4 and 13. Pos. ang. 320°. Dist. 37″. White and blue.

α^2 *Capricorni.*—R.A. = 20^h 11^m. Dec. = + 12° 55′. Mag. 3 and 13½. Dist. 5″. Companion in turn double, 13½ and 14. Pos. ang. 250°. Dist. 1·8″. A fine test for large telescopes.

1 *Delphii.*—R.A. = 20^h 24^m. Dec. = + 10° 30′. Mag. 6, 11½, and 14. Pos. ang. 342° and 359°. Dist. 0·9″ and 15″. A most difficult object.

ε *Equulei.*—R.A. = 20^h 53^m. Dec. = + 3° 50′. Mag. 5½, 6, and 7½. Pos. ang. 288° and 78°. Dist. 0·8″ and 11″. Yellow, yellow, and blue. The close pair a fine binary.

γ *Equulei.*—R.A. = 21^h 5^m. Dec. = + 9° 39′. Mag. 5, 11, and 13½. Pos. ang. 277° and 10°. Dist. 2·1″ and 42″. Yellow, blue, and blue.

τ *Cygni.*—R.A. = 21^h 10^m. Dec. = + 37° 22′. Mag. 5 and 8. Pos. ang. 150°. Dist. 1″. A rapid binary.

β *Aquarii.*—R.A. = 21^h 25^m. Dec. = – 6° 6′. Mag. 3 and 13. Pos. ang. 320°. Dist. 25″. Difficult.

ζ *Aquarii.*—R.A. = 22^h 23^m. Dec. = – 0° 38′. Mag. 4 and 4½. Pos. ang. 334°. Dist. 3·7″. Yellow.

π *Cephei.*—R.A. = 23^h 4^m. Dec. = + 74° 44′. Mag. 5 and 9. Pos. ang. 24°. Dist. 1·3″. Yellow and purple.

ο *Cephei.*—R.A. = 23^h 14^m. Dec. = + 67° 27′. Mag. 6 and 9. Pos. ang. 194°. Dist. 2·5″. Orange and deep blue.

σ *Cassiopeia.*—R.A. = 23^h 53^m. Dec. = + 55° 5′. Mag. 6 and 8. Pos. ang. 324°. Dist. 7″. White and green.

The above form a catalogue of some eighty-six double stars, which are either of especial interest from their colours or characters, or are else of use for testing the capabilities of both telescope and observer. Some of the binary stars move so rapidly in both position angle and distance, that in the space of a few years the values given in the catalogue for the Epoch 1884 will be found to be no longer accurate;

but in the greater number the stars move so slowly that the above value will be found true for many years to come.

It has already been observed that the binary stars are known to be systems of double or multiple suns, moving round their common centre of gravity, and according to the known laws of gravitation. The orbits of many of these stars have been regularly computed, and found to agree well with the actual motion of the system, thus conclusively proving that the law of gravitation holds good all over the universe. The principal of these binaries are the folowing :—

Binary stars

	Period years.	Epoch of Periastron.	Semi-axis Major.
ζ Herculis	34·6	1864·9	= 1·36″
η Coronæ	40·2	1849·9	= ·99″
ξ Ursæ	60·6	1875·5	= 2·54″
ζ Cancri	62·4	1869·3	= ·90
70 Ophiuchi	92·8	1807·9	= 4·88
γ Virginis	175·0	1836·5	= 3·39
η Cassiopeæ	222·4	1909·2	= 9·83
λ Ophiuchi	234·0	1803·9	= 1·19
μ^2 Bootis	280·3	1863·5	= 1·47
γ Leonis	402·6	1741·1	= 2·00
δ Cygni	415·1	1904·1	= 2·31

All the above stars are contained in the list which has been given.

CHAPTER XXII.

VARIABLE AND TEMPORARY STARS.

Variable Stars—Explanation of Variations—New and Temporary Stars.

WHEN carefully examined, a considerable number of stars have been found to undergo slight variations in brightness, as if from time to time they were liable to some change which tended to periodically lessen their brilliancy. But in most cases these changes are very small in amount, and are somewhat irregular in their occurrence. In a considerable number of instances, however, these variations in brightness are very large in amount and very regular in their periods. The following are the principal of these stars which are visible to the naked eye.

Variable stars.

β *Persei.*—R.A. = $3^h\ 0^m$. Dec. = + 40° 30′. Changes from 2·5 mag. to 4 mag. in 2·86 days. It is usually of the 2¼ mag., and after remaining so for 2½ days, it falls to the 4th mag. in the short space of 4¼ hours, and remains so for 20^m, and then commences to regain its brilliancy ; and 3¼ hours later is again of the 2½ mag.

δ *Cephei.*—R.A. = $22^h\ 25^m$. Dec. = + 57° 48′. Changes from 3·7 mag. to 4·8 mag. in 5·36 days.

η *Aquila.*—R. A. = $19^h\ 47^m$. Dec. = + 0° 44′. Changes from 3·6 mag. to 4·7 mag. in 7·17 days.

β Lyræ.—R. A. $=18^{h}$ 46^{m}. Dec. = + 33° 13′. Changes from 3·5 mag. to 4·5 mag. in 12·91 days.

ο Ceti.—R. A. = 2^{h} 13^{m}. Dec. = − 3° 31′. Changes from 2 mag. to 10 mag. in 3·30 days.

This star is *Mira* Ceti. At its maximum brilliancy it shines like a star of the 2nd mag., and then gradually decreases for some seventy-four days, until it is no longer visible to the naked eye, and continues to decrease in brightness till of only the 10th mag., or with less than one thousandth part of its former brightness. It remains invisible to the naked eye for over two hundred days, then it reappears, and in forty-three days has recovered its maximum brightness. Its brilliancy at its maximum and its period are subject, however, to very considerable and irregular variations.

ν Hydræ.—R.A. $=13^{h}$ 23^{m}. Dec. = −22° 32′. Changes from 4 mag. to 10 mag. in 436 days.

η Argus.—R.A. $=10^{h}$ 41^{m}. Dec. = −58° 57′. Changes from 1 mag. to about 7½ mag. in some seventy years. Its supposed period must be very irregular. In 1843 it shone very brightly, but at present is only of the 7½ magnitude.

Amongst the telescopic stars there is a very considerable number of variables, some being stars of the 7th or 8th mag., which fade either quite out of view or down to the 13th or 14th mag. It is a noteworthy fact that most of these stars are red in colour, quite a number being deep-red, or even crimson. These variables are commonly designated by the capital Roman letters, as R Leporis, R Leonis, T Scorpii, S Herculis, etc.

Explanation of variations.

No sound explanation of the cause of these variations has as yet been devised. It has been supposed that in some cases they may be due to the periodical formation of enormous masses of sun spots. Our own sun must from this cause undergo slight variations in brilliancy. But this could only explain very small variations in brightness. For a fall of brightness of only one magnitude would necessitate at least three-fourths of the surface being supposed covered with sun spots—a most unlikely circumstance. Others have suggested the passing of one or more opaque bodies before the star, as a planet or a dense flight of meteors; this hypothesis might explain some of the known cases, but only a very few. For the present, however, we must await further information before any feasible theory can be advanced to account for these remarkable variations in the brightness of these stars.

Temporary Stars.—Besides those stars which undergo known periodical variations in brightness, a number of instances are known where bright stars have suddenly made their appearance, and after shining brightly for some time, have gradually faded away, either quite out of sight, or until very faint. Some of the more remarkable cases have been already referred to on page 54—the most famous being that observed in Cassiopeia, by Tycho Brahé, in 1572, when the new star shone brighter than Jupiter, and that observed in Ophiuchus, in 1604, which shone brighter than even Venus. Of late times a number of additional instances have been witnessed, though none approaching those just referred to. In 1848 Hind discovered such a star in Ophiuchus (R.A. $=16^{h}$ 54^{m}, Dec.

12° 36′); it shone at its maximum as a star of the 4th mag., but gradually faded away until only of the 11th mag.

New temporary stars.

Another instance was in the case of T Coronæ (R.A. = 15^h 54^m, Dec. = + 26° 16′), which was discovered by Birmingham, in May 1866, as a 2nd mag. star which soon faded away to about the 10th mag. The spectroscope showed that the probable cause of the outburst of light in this star was due to the incandescence of immense quantities of hydrogen gas. In November, 1876, Schmidt discovered a new star in Cygnus (R.A. = 21^h 37^m, Dec. = + 42° 16′). It shone at first like a star of the 3rd mag., but rapidly faded away to the 12th mag. It is most remarkable that this body now gives the spectrum of a mass of gas exactly analogous to the spectrum of a planetary nebula; and it has been supposed that we have here an instance of a sun being converted into a nebula through being rendered highly incandescent by some unknown cause. It is not improbable, however, that it was merely another instance of a temporary star appearing within a nebula. In 1860 such a star was seen in a nebulous cluster in Scorpio, and in 1885 such a new star suddenly appeared in the great nebula in Andromeda, shining like a star of the 6th magnitude, and then gradually fading away.

CHAPTER XXIII.

THE STARS AS SUNS.

Proper Motions—Motion of Solar System—List of Large Proper Motions—Stars with Common Proper Motion—In Widely Separated Systems—Motion in Line of Sight—Parallax—List of Large Parallaxes—Star Masses—Star Clusters—Star Systems—List of Star Clusters.

Proper motions of stars.

It has long been known that many of the principal stars in the heavens possess actual motions of their own, independent of the apparent motion they all have in common, due to the slow change in the position of the earth's axis. The stars are not absolutely fixed in position, as was originally believed, but are very slowly moving in the heavens, and this slow motion is called their "*Proper Motion.*" By comparing the relative places of the stars as carefully determined from two series of observations separated by a long interval of time, it has been found possible to approximately determine the amount of this proper motion in the case of a considerable number of stars. As a rule this proper motion is a very small quantity, rarely more than a very small fraction of a second of arc in a year, but in some few cases it is much more, showing that some stars are very rapidly moving through space. And the consideration of these proper motions has already led to some very interesting speculations regarding the constitution of the universe. Thus it has been found that the average proper motion of the stars seems to decrease with their brightness, which is what might be anticipated were the average distance of the fainter stars greater than the average distance of the brighter ones. For instance, the average proper motion of the 48 stars of the second magnitude is nearly 2½ times as great as the average proper motion of the 313 stars of the fourth magnitude, just as might be anticipated from the consideration that the difference in brightness of the two classes of stars would lead to the conclusion that the average distance of a star of the fourth magnitude would be about 2½ times the distance of a star of the second magnitude.

Relation between proper motion and distance.

It is true that the stars having the greatest proper motion are mostly faint stars, but this is not inconsistent with the relationship which has just been referred to, for as the number of faint stars is so much greater than the number of bright ones, a much wider range might be expected amongst the amounts of the individual proper motions.

Explanation of proper motion.

These alterations in the position of the stars might arise from one or both of two causes: from a real change in the position of the stars, due to their actual motion in space; or from an apparent change in their positions, due to an actual motion of our solar system in space,—for if the stars be supposed to be moving, why not our own sun which is merely a similar body? There would be no difficulty, however, in distinguishing between the motion due to these two causes; for that due to any motion of our sun in space would be symmetrically distributed in opposite directions on either side of the path of the sun in space whereas no such symmetrical distribution could be expected in that due to the actual motion of the stars.

Motion of solar system.

By considering the general tendency of the direction of the proper motions of the stars, several attempts have been made to determine the direction and amount of any motion of the solar system. All agree in fixing on some point within the constellation Hercules—somewhere, probably, between ρ and λ Hercules—as the point towards which the sun is moving. The rate of this motion is by no means so certainly fixed, but would appear to be about one hundred and fifty million miles per annum, or five miles per second.

It was supposed by Mädler that the solar system might be only one of a great system of suns revolving round their common centre of gravity, or even round one great central sun; and he was led to suppose that this central luminary might be *Alcyone*, or η Tauri, the brightest of the Pleiades. Our present knowledge of the proper motion of the stars, however, is not sufficiently great to enable any real conclusion being drawn on such points as these, but in time data will be gradually accumulated, which will lead to our being able to determine whether there is any probability of the truth of such a striking hypothesis, that the entire universe may be members of one grand system, ruled over by one giant central member.

The stars possessing the largest proper motions are given in the following list, excluding, however, one or two doubtful cases:—

Catalogue of proper motion.

Groombridge 1830, 6½th mag. A small star in Ursa Major. Proper motion = 7·1″.

Lacaille 9352, 7½th mag. Proper motion = 7·0″.

Cordoba Zone XXIII, 1584, 8½th mag. Proper motion = 6·2″.

61 Cygni, 5½th and 6th mag. The well-known double star in Cygnus. Common proper motion = 5·1″.

Weisse Bessel X 1112, 8½th mag. A small star in Ursa Major, between 47 and ψ. Proper motion = 4·7″.

ε Indi, 5½th mag. Proper motion = 4·6″.

Weisse Bessel X 1174, 7½th mag. A small star about 7° south of the last but one, between 47 and ξ Ursæ Majoris. Proper motion = 4·4″.

o^2 Eridani, 4th mag. Proper motion = 4·0″.

α Centauri, 1st mag. Proper motion = 3·8″.

μ Cassiopeiæ, 6th mag. Proper motion = 3·7″.

e Eridani, 4½th mag. Proper motion = 4·0″.

These twelve stars are the only well authenticated ones whose proper motions exceed 3″ per annum. Of these, four have had their parallaxes carefully determined, so that their real motion can be ascertained. These are 61 Cygni, α Centauri, μ Cassiopeiæ, and ε Indi. These stars would appear to be moving at the respective rate of some nine, four, ten and nineteen hundred million miles per annum, or at the rate of thirty, fourteen, thirty-three, and sixty-three miles per second. All these are considerably greater than the supposed motion of the solar system, which is only five miles per second. The parallax of the star Groombridge 1830 has not yet been satisfactorily ascertained, but it would appear to be very small, so that this star must be moving with enormous velocity, probably from two to three hundred miles per second.

Motion in miles.

The stars which follow, all have large proper motions, though not so great as those previously given:—

34 Groombridge, 8th mag. Proper motion = 2·8″.

β Hydri, 3rd mag. Proper motion = 2·5″.

ζ Toucani, 4th mag. Proper motion = 2·3″.

α Boötis, 1st mag. Proper motion = 2·2″. It was the apparent change in the relative place of this star which first led Halley to suspect the existence of the proper motion of the stars, for it seemed to be a degree farther north than the place assigned by the early astronomers. Yet other neighbouring stars had not changed. Cassini was soon able to prove the reality of this motion by comparing it with its neighbour η Boötis, whose position remained unchanged.

Piazzi II. 123, 6th mag. A small star about a degree north of the well-known double ν Ceti. Proper motion = 2·2″.

B A C 8083, 6½th mag. A small star in Cassiopeiæ. Proper motion = 2·1″.

Piazzi XIV. 212. A well-known double star in Libræ. Mags. 6 and 8. Distance 10·3″. Common proper motion = 2·0′.

τ Ceti, 3½th mag. Proper motion = 1·9″.

σ Draconis, 5th mag. Proper motion = 1·9″. As the parallax of this star = 0·24″, its proper motion corresponds to a motion of eight times the radius of the earth per annum, or about twenty-four miles per second.

δ Pavonis, 5th mag. Proper motion = 1·8″.

ζ^1 and ζ^2 Reticuli. A wide pair of 5½th mag. stars, with a common proper motion = 1·5″.

α Canis Majoris, 1st mag. Proper motion = 1·4″.

α Canis Minoris, 1st mag. Proper motion = 1·4″.

Orbital motion of Sirius.

Besides their large proper motions, there is reason to believe that both these stars are moving in orbits round large dark companions, or rather round the common centre of gravity of the system. In the case of *Sirius*, a 10th mag. companion, now distant 10·8″, has been discovered, which has been supposed to be the dark companion, only imperfectly reflecting the light of its primary. It has only moved, however, through an arc of some 30° since its discovery, so that it has not yet been found possible to decide whether this companion will account for the orbital motion of Sirius, or whether there may be other hitherto undiscovered companions. As the parallax of Sirius is about 0·25″, it follows that this known companion is about forty-four times the mean distance of the earth from its primary. This companion appears to have a period of revolution of about 50 years, at a mean distance of about 7″, so that it would indicate that the combined mass of Sirius and its satellite is about nine times as great as the mass of our sun. No such companion has as yet been discovered to *Procyon*, which exhibits similar variations in its proper motion, indicating that it also is revolving in an elliptical orbit. Procyon is probably twice as far as Sirius from us, so that a similar companion would be closer to its primary and probably much harder to see.

γ Serpentis, 5th mag. Proper motion = 1·3″.

θ Ursæ Majoris, 3rd mag. Proper motion = 1·2″.

A Ophiuchi. A pair of 5th mag. stars with a common proper motion = 1·2″.

30 Scorpii, 8th mag. Proper motion = 1·2″.

η Cassiopeiæ, a well-known binary double star, mag. 4 and 7½, moving in an orbit of mean distance 9·83″, and period 222 years, with a common proper motion of 1·2″. Its parallax being 0·15″, it follows that it is moving in an orbit with about sixty-four times the radius of that of the earth, so that the combined mass of the two stars must be about five times as great as that of the sun, whilst the proper motion indicates that the whole system is moving in space with a velocity of twenty-four miles per second.

70 Ophiuchi. Another fine binary double star, mag. 4½ and 7, with an orbit of mean distance 4·88″, and period 80 years, the common proper motion being 1·1″. Hence as its parallax is 0·16″, the system would appear to be moving through space with a velocity of twenty miles per second, whilst revolving in an orbit thirty times as large as that of the earth's, or about equal to that of Neptune. The combined masses of the two stars would seem to be about equal to four times that of our sun.

Common proper motions.

When the proper motion of the stars comes to be critically examined, a number of cases are found which seem to indicate some physical connection between two or more widely separated stars. A most marked instance of this occurs in the case of four stars in the southern hemisphere, all contained in the previous list—namely, ζ Toucani, ε Eridani, ζ^1 and ζ^2 Reticuli. The two latter are quite close together, but are distant by 19·4° and 19·5° from the two others, which are in turn about 33·1° apart. All these seem now moving through space with a very large common proper motion, and at the same time slowly separating from

Widely separated systems of stars.

each other, at rates nearly proportional to the distance now separating them. This would lead to the conclusion, therefore, that in the distant past, perhaps sixty thousand years ago, all four must have been close together, and forming a fine quadruple star. They thus seem to have formed parts of one common system, broken up by some unknown cause, and now steadily moving away through space. Other similar cases of apparent connection between widely separated stars are also known, five of the principal stars in Ursa Major forming an instance pointed out by Proctor.

Motion of stars in line of sight.

The rate of motion of the stars shown by their proper motion does not represent their actual motion in space, but only the portion of that motion which is at right angles to the line between us and the star. Any motion of approach or recession from us would not be visible in this way. Huggins, however, has applied the spectroscope to the detection of any motion of the stars along the line of sight. Thus, if a star is approaching us, the light-waves will be compressed or shortened by the advancing motion of the star, so that any line in its spectrum will seem to be shifted towards the violet end, and *vice versâ* if the star be receding. Hence, by comparing the spectrum of the star with that of the sun, or incandescent hydrogen, it is possible to show not only whether a star is approaching or receding from us, but to approximately determine the rate of its motion. This has now been done by Huggins and by Christie for a considerable number of stars. The principal results are :—

Stars approaching us, with their motion in miles per second.

α Andromeda	= 33	β Geminorum	= 26
α Ursæ Majoris	= 27	Arcturus	= 33
α Herculis	= 31	α Lyræ	= 34
α Cygni	= 43	α Pegasi	= 34

Stars receding from us.

α Persei	= 25	α Tauri	= 20
α Aurigæ	= 27	β Orionis	= 18
α Orionis	= 21	Sirius	= 20
α Geminorum	= 25	Procyon	= 24
α Leonis	= 26	α Coronæ	= 40
α Ophiuchi	= 17	ε Pegasi	= 15

It is apparent that these rates of motion are in accord with those deduced from the proper motions of the stars.

Annual parallax of stars.

Reference has already been made to the parallax of the stars, this parallax being the angle subtended by the radius of the earth's orbit at the distance of the star. The parallax of a number of stars has been determined with some approach to accuracy, though the work is one of excessive difficulty on account of the exceeding minuteness of the parallax of the stars. One second of arc is a very minute quantity, but a parallax of 1″ would show that a star was at the enormous distance of twenty millions of millions of miles, or over two hundred thousand times as far away as the sun,—a distance so immense that even light, travelling as it does with such great velocity, would require some three years to traverse it. Yet no star has been discovered to have so great a parallax as a whole second of arc, the greatest known parallax, that of α Centauri, being only 0·95″.

The stars whose parallax is best known appear to be the following :—

34 Groombridge	8th mag.	Parallax	= 0·31″
η Cassiopeiæ	4th mag.	,,	= 0·15″
μ Cassiopeiæ	6th mag.	,,	= 0·34″
α Aurigæ	1st mag.	,,	= 0·30″
Sirius	1st mag.	,,	= 0·25″
Procyon	1st mag.	,,	= 0·12″
Weisse Bessel, 112	8th mag.	,,	= 0·50″
ε Indi	5½th mag.	,,	= 0·22″
Arcturus	1st mag.	,,	= 0·13″
α Centauri	1st mag.	,,	= 0·95″
70 Ophiuchi	4th mag.	,,	= 0·16″
α Lyræ	1st mag.	,,	= 0·18″
σ Draconis	5th mag.	,,	= 0·24″
61 Cygni	5½th mag.	,,	= 0·50″
6 Cygni	6th mag.	,,	= 0·48″
Groombridge, 1618	7½th mag.	,,	= 0·32″
Lacaille, 9332	7½th mag.	,,	= 0·28″
Lalande, 21,258	8th mag.	,,	= 0·27″

From this list it is evident that many of the first magnitude stars have annual parallaxes of about one-fifth of a second. A sufficient number of these parallaxes have not as yet been determined to enable it to be ascertained whether they show the same law as the proper motions, and indicate that though many of the fainter stars may be nearer to us than those brighter, yet that, considering them as a whole, the average distance of the fainter stars is greater than the average distance of the brighter ones.

Masses of the stars.

From some photometric measurements which have been made it would seem that the average brightness of a star of the first magnitude is about ten thousand millionths of the brightness of the sun. If therefore the sun was transported from us to even the average distance of a star of the first magnitude it should shine like a comparatively insignificant star, so that it is far from being one of the brightest luminaries of the stellar host. From the knowledge we have gained of the masses of the binary stars whose parallax has been determined, it would seem that most of the stars have masses of from three to ten times as great as that of our sun.

Star clusters.

Some of the most remarkable features in the heavens are presented by the great clusters of stars which have been discovered in different portions of the heavens. In small telescopes and with low powers these clusters of stars cannot be distinguished in appearance from the nebulæ, but in larger telescopes and under higher powers their true nature becomes apparent, many of them being resolved into clusters of thousands of minute stars. For this reason it was at one time believed that all the nebulæ were merely clusters of stars, only that some were too far off for them to be resolved into stars even in the finest instruments. The spectroscope has shown, however, that many of these supposed irresolvable clusters of stars are really masses of glowing gas, and apparently entirely different in character from the star clusters.

Systems of stars.

The real character of these clusters of stars is still uncertain: they may be merely great groups of stars which are much closer to each other than is commonly the case, and hence appear all clustering together; or they may be great systems of suns, all moving round their common centre of gravity, and much more intimately connected with each other than is commonly the case with different stars in the universe. The tendency in many cases for these stars to have the same magnitude, or to be commonly of some one magnitude but grouped round one or more larger stars, would seem to favour the idea that they were really systems of stars all closely grouped together under some physical link. And though the term "close" is here used, it must only be understood in a relative sense; the stars may seem to be only a few tenths of a second apart, but these few tenths of a second probably correspond to many hundred or even thousand times the distance of the earth from the sun.

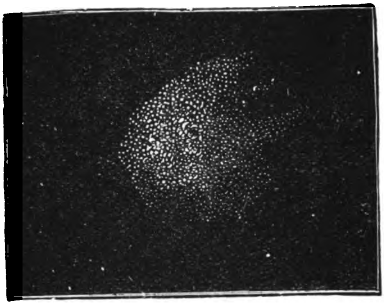


FIG. 72.—CLUSTER 3 M IN CANES VENATICI.

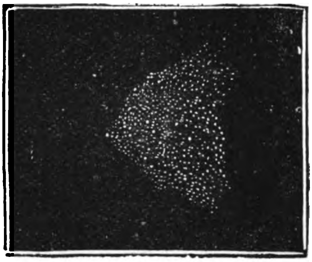


FIG. 73.—CLUSTER 35 M IN GEMINI.

Telescopic appearance.

In small telescopes, or in larger telescopes under small magnifying power, these clusters appear like dull spots of cloudy light, indistinguishable from the true nebulæ; but when the telescope is of adequate aperture, as the magnifying power is increased these cloudy spots of light begin to change in character. They commence to sparkle as it were, minute glittering specks can be detected as if the whole were strewn with diamond dust; and as higher powers are used, the whole gradually resolves itself into thousands of glittering points of light, and they are visible in their true character as great clusters of minute brilliant stars. In some cases this resolution into stars only occurs in the finest telescopes; but in a great number of cases even telescopes of moderate power will resolve these clusters into grand groups of very minute glittering stars, usually of from the 10th to the 14th standard magnitude.

The following is a list of the more interesting of these clusters. In it the letter M stands for Messier, and shows that the number following is the number in Messier's original Catalogues of Nebulæ and Clusters. A number without a letter is the number of the cluster in Sir John Herschel's great Catalogue of Nebulæ and Clusters.

List of star clusters.

M 37. R. A. = 5^h 44^m. Dec. = + 32° 22′. In Aurigæ. A grand cluster of nearly a thousand yellowish stars, principally of the 11th and 12th mag.; many apparently arranged in streams and festoons.

M 35. R. A. = 6^h 1^m. Dec. = + 24° 21′. In Geminorum near ε. A mass of small stars of all magnitudes, with a diameter of about 20′, and forming a gorgeous object in large telescopes.

M 41. R. A. = 6^h 42^m. Dec = – 20° 37′. In Canis Major, 4° south of *Sirius*. A fine group with a reddish star near the centre.

M. 44. R. A. = 8^h 33^m. Dec. = + 20° 22′. In Cancer. The "Præsepe" of the ancients, being visible to the naked eye as a mass of minute stars.

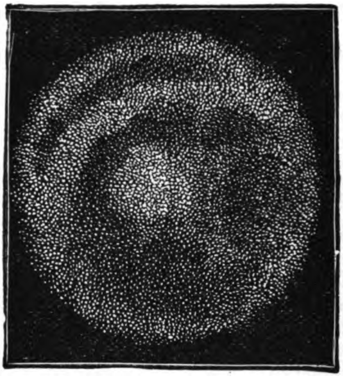


FIG. 74.—51 M IN CANES VENATICI. THE SPIRAL NEBULA.

M 51. R. A. = 13^h 25^m. Dec. = + 47° 29′. In Canes Venatici. The so-called spiral nebula. In ordinary telescopes resembles a dull misty spot, a little brighter towards one edge; but in Lord Rosse's great telescope seems to have a wonderful spiral structure. Might have been supposed to have been a real gaseous nebula, but, according to the spectroscope, consists of excessively minute stars. This, however, is not conclusive in such a case, for the reason given under 31 M.

M 3. R. A. = 13^h 37^m. Dec. = +28° 58′. A great mass of minute stars, mainly 11th and 12th mag., forming a grand globular cluster.

M 80. R. A. = 16^h 10^m. Dec. = – 22° 42′. Half-way between α and β Scorpii. Under low powers resembles a comet in appearance, but easily resolved into a grand mass of 12th mag. stars. Within it appeared in 1860 a temporary star, blazing up to the 7th mag., and then rapidly fading away until no longer distinguishable.

M 13. R. A. = 16^h 37^m. Dec. = + 36° 41′. The great cluster of Hercules, lying about one-third of the way from η towards ζ. A magnificent cluster easily resolved by any telescope of greater aperture than six inches. In large instruments seems to consist of a great globular cluster of many thousand stars, ranging from the 10th to the 14th mag., even if not beyond. It is traversed by several dark rifts or markings.

M 92. R. A. $= 17^{h} 13^{m}$. Dec. $= + 43^{\circ} 16'$. A fine cluster, also in Hercules, of similar character to the last, but seems to consist of brighter stars more closely packed, so that it is not so easily resolved. Towards the centre it is very bright, indicating its globular form.

M 22. R. A. $= 18^{h} 29^{m}$. Dec. $= - 34^{\circ} 0'$. Between μ and σ Sagittarius. A fine but coarse cluster, principally of 10th *and* 13th mag. stars, with but few of intermediate brightness. It is bright and easily resolved.

M 15. R. A. $= 21^{h} 24^{m}$. Dec. $= +11^{\circ} 38'$. North-west of ϵ Pegasi. A bright cluster of 12th mag. stars, easily resolved, and very bright in the centre.

M 2. R. A. $= 21^{h} 27^{m}$. Dec. $= - 1^{\circ} 22'$. In Aquarius, north of β. A fine round nebulous object about 5′ in diameter, consisting of a globular cluster of innumerable 13th mag stars.

M 30. R. A. $= 21^{h} 34^{m}$. Dec. $= - 23^{\circ} 42'$. In Capricornus. A moderately bright nebulous cluster, resolvable into innumerable 12th mag. stars. Close to it is an 8th mag. star forming a fine contrast.

To the above perhaps may be added the following, whose exact nature is uncertain; for whereas it possesses all the appearance of being a true nebula, yet its spectrum would appear to be continuous, indicating it to be rather an enormous cluster of excessively minute stars very closely condensed :—

M 31. R. A. $= 0^{h} 26^{m}$. Dec. $= + 40^{\circ} 35'$. The great nebula of Andromeda, readily visible to the naked eye as a dull spot of light close to ν Andromeda, and nearly half-way between α and γ. It appears like a long oval mass of light, bright towards the centre and gradually fading away on all sides ; near it are a considerable number of very faint stars, and traversing it have been seen several dark rifts. Its whole appearance is that of a nebula, perhaps a mass of gas so condensed that its spectrum is continuous, and not, as usual, one composed of bright lines. The possibility of this always renders it difficult to be sure whether a body of this character is gaseous or not. In 1885 a bright temporary star made its appearance near the centre of this nebula, but has since faded.

CHAPTER XXIV.

THE NEBULÆ.

Nebulæ—List of Principal Nebulæ—Nature of Nebulæ—Constitution of Nebulæ.

Distinction between nebulæ and clusters.

THE spectroscope has shown these bodies to be immense volumes of gas, sometimes of very complicated structure through partial condensation, but often consisting of simple spherical or ellipsoidal form. They can only be distinguished from the fainter irresolvable clusters by the aid of the spectroscope, which shows the clusters to have the continuous spectrum emitted by incandescent solids or liquids, whilst the nebulæ give a spectrum of bright bands or lines such as is emitted by a mass of glowing gas. Owing to the difficulty and often impracticability of observing the spectrum of the fainter nebulous bodies, it has been found impossible to determine the real character of the vast majority of those known—over ten thousand in number; but there is reason to believe that most are true nebulæ, and not faint star clusters.

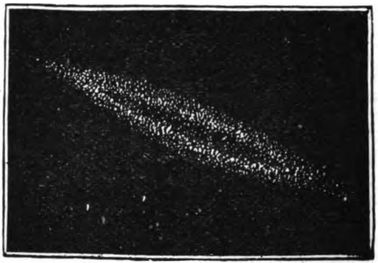


FIG. 75.—31 M IN ANDROMEDA.

The more interesting of the brighter nebulæ are the following:—

List of nebulæ.

M 1. R. A. = 5^h 27^m. Dec. = —21° 56′. The so-called "Crab Nebula," in Taurus. An oblong, faint mass, which in powerful telescopes is seen to possess an extraordinary complex character, being one mass of streams of condensed nebulous matter.

M 42. R. A. = 5^h 29^m. Dec. = —5° 28′. The great Nebula of Orion. A most magnificent object, and in a good telescope perhaps the finest and most gorgeous in the heavens. It covers an area of four or five square degrees, and can be readily detected with the naked eye; yet, strange to say, it was quite overlooked by Galileo, though he paid much attention to Orion.

In the centre of the nebula is the famous trapezium of Orion, the multiple star θ Orionis, consisting of four stars of the 6th, 7th, 7½th, and 8th mag., arranged in the form of an oblique trapezium, whilst two other minute stars of about the 11½th mag. lie without the trapezium but close to the sides and also to the two brighter stars. One or two still fainter stars have been suspected.

This nebula has been carefully drawn by several astronomers, though the different delineations are not quite in harmony with each other. Lately it has been finely photographed. The whole extent of the nebula is filled with stars of different magnitudes ranging from the 7th downwards, but it is quite unknown whether they form part of the same system as the nebula or are merely seen in front of or through it. The spectroscope shows that the nebula itself is a great mass of gas.

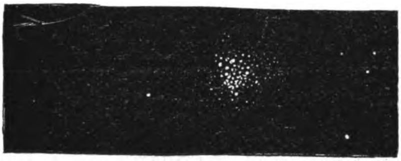


FIG. 76.—CLUSTER 15 M IN PEGASUS.

1532. R. A. = $7^h\ 22^m$. Dec. = + 21° 9′. Close to δ Andromeda. An example of a very interesting class of bodies, a nebulous star. Consists of an 8½th mag. star, surrounded by a small circular nebula, forming probably a globular envelope to the star. From the drawings it would seem to be a star surrounded by a spherical envelope of glowing gas, some 25″ in diameter.

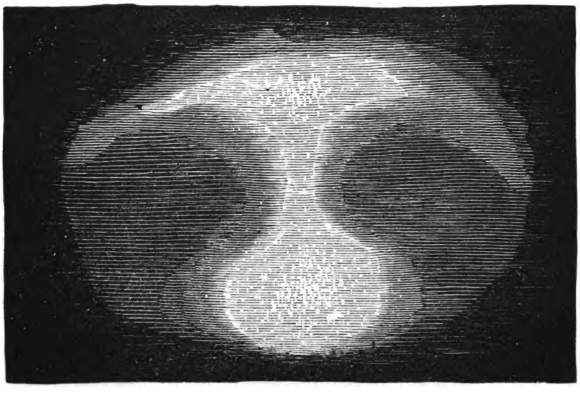


FIG. 77.—27 M, THE DUMBBELL NEBULA.

2008. R. A. = $9^h\ 59^m$. Dec. = − 7° 7′. In Sextans. A very distinct nebula, much condensed and brighter towards its centre.

2102. R. A. = $10^h\ 19^m$. Dec. = − 18° 2′. A fine planetary nebula, 2° south of μ Hydræ. A bright elliptical disc of pale blue light, about 40″ in diameter. Larger telescopes show traces of condensed points of light within it.

M. 97. R. A. $= 11^h 8^m$. Dec. $= + 55° 40'$. South east of β Ursæ Majoris. A large faint planetary nebula, $2' 40''$ in diameter. In powerful telescopes it is seen to contain two round darker spots, one containing a faint star, whilst traces of a spiral character are noticeable.

4234. R. A. $= 16^h 38^m$. Dec. $= +24° 1$. In Hercules. A very bright small planetary nebula of bluish colour, about $8'$ in diameter, and much resembling a star out of focus.

4355. R. A. $=17^h 55^m$. Dec. $=-23° 2'$. The Trifid Nebula, near μ Sagittarii. A remarkable object resembling a circular nebula condensed towards the centre and divided into three portions by dark rifts meeting in the centre. Full of minute bright stars which render difficult the detection of its gaseous character.

4373. R. A. $= 17^h 59^m$. Dec. $= + 66° 38'$. In Draco, half-way between Polaris and γ Draconis. A bright blue elliptical planetary nebula, with a very minute stellar nucleus. The first nebula whose gaseous character was discovered by Huggins.

M 17. R. A. $=18^h 14^m$. Dec. $= - 16° 15'$. The Horse-shoe Nebula, about 5° north of μ Sagittarii. Its most conspicuous portion somewhat resembles a horse-shoe in form, but there are great outlying masses of fainter nebula. Both within and on all sides are numbers of brilliant stars.

M 57. R. A. $=18^h 49^m$. Dec. $=+32° 52'$. The Ring Nebula, in Lyræ, between β and γ Lyræ. A bright elliptical ring filled with fainter nebulous matter and without any trace of even the faintest star within it. A faint 12th mag. star lies near its eastern edge. One of the most remarkable and interesting nebulæ in the heavens.

M 27. R. A. $= 19^h 54^m$. Dec. $= + 22° 23'$. The Dumb-bell Nebula, in Vulpecula, about 4° north of λ Sagitta. An elliptical nebula with a brighter condensed portion in the shape of a dumb-bell lying within. It is surrounded by a number of faint stars, and nine or ten can be seen within the nebula itself, in this respect forming a remarkable contrast to the last.

4628 R. A. $= 20^h 58^m$. Dec. $= - 11° 50'$. Near ν Aquarii. An elliptical planetary nebula, about the size of Saturn, and exceptionally bright. Within it there has been detected a bright elliptical ring.

Nature of nebulæ.

Much interesting speculation has been evolved as to the true nature and constitution of these nebulæ, especially since it has been demonstrated that they are composed, at least mainly, of immense, volumes of glowing gas. In a number of cases, these volumes of gases must exceed in dimension the whole known solar system. Some indeed, must be immense ellipsoidal masses, whose greater diameter must be many hundred times the diameter of the terrestrial orbit. It is not difficult to conceive of the existence of these great volumes of gas; what has seemed so extraordinary is their retaining a sufficiently high temperature to enable them to glow, and to retain the extraordinary forms which some seem to possess.

But are these great volumes of gas really incandescent, or even at a high temperature? It does not necessarily follow that they are because they give a bright-line spectrum. There exist good reasons for believing that any large volume of gas, even at ordinary temperatures, would show a bright-line spectrum if only a sufficient thickness were present. These immense masses of gas may be therefore at a comparatively low temperature—lower even than that of our terrestrial atmosphere. But it would not be difficult to imagine them kept at much higher temperature than this by the effect of a slow condensation, due to the presence of some small denser nucleus. If this nucleus were comparatively large, it might give rise to a condensation which would maintain the entire interior of the nebula at high temperature and leave only a shallow external envelope at a lower temperature. In any of these ways might be explained the bright-line spectrum given by these nebulæ. The permanency of some of the remarkable forms shown by the nebulæ would be far harder to explain, unless it be supposed that they are grouped round numerous stellar nuclei. And it is remarkable that it is very rarely any of these characters manifest themselves in those nebulæ wherein evidence exists of the presence of these nuclei.

Glowing masses of gas.

It may be assumed, therefore, that these nebulæ are great masses of gas, whose temperature is maintained by their slow condensation. As this slow condensation proceeds it becomes more and more rapid, the temperature of the whole rapidly rises, and after a time an intensely heated incandescent nucleus is formed, and the nebula becomes a star. The nebulæ may be regarded, therefore, as stars *in futuri*, and the condition of a nebula may be regarded as the earliest phase in the history of those numerous masses of matter constituting the stars,—as one of the earliest stages in the history of a solar system.

Constitution of nebulæ.

CHAPTER XXV.

THE TELESCOPE.

Refractors — Reflectors — Mountings — Altazimuth—Equatorial—Simple Equatorials — Complete Equatorials—Employing the Telescope — Magnifying Powers—Micrometers—Seeing—Recording.

OWING to the great advances which have been made within the last twenty years in the art of constructing telescopes, especially through the introduction of the new silver-on-glass reflecting telescopes, it is now possible to obtain for a comparatively small sum an astronomical telescope equal in power to the finest instruments that were in use at the middle of the present century. For in the year 1850 the telescopes in common use were ordinary achromatic refractors of from four to five inches aperture, those having apertures of as much as seven inches being considered exceptionally fine and powerful, whilst there were very few good instruments exceeding ten inches in aperture. Now, by far the greater number of telescopes in use are silver-on-glass reflecting telescopes with apertures ranging between six and nine inches, whilst instruments of from ten to twelve inch aperture are quite common. The older forms of reflecting telescopes were usually much inferior in power and performance to the ordinary achromatic refractor, but these new silver-on-glass reflectors are in every way quite as powerful as the far more costly refractor, whilst from their shorter focal length they are more conveniently mounted and managed.

At the present time, therefore, there are two classes of telescopes—the Refractors, constructed with an achromatic object-glass; and the Reflectors, constructed with a glass speculum or mirror coated on its upper surface with a highly polished film of silver, and almost invariably Newtonian in form.

Refractors and Reflectors.

The question,—Which form offers the greater advantages?—is one which has not yet been definitely settled, and indeed is a question to which the answer may differ according as it refers to large or small instruments. The refractor possesses the advantage that when once adjusted it will rarely require readjustment, and will be always ready for use when wanted, even though it may have been lying idle for a long time. Moreover, its optical portion is not easily put out of proper adjustment by any ordinary treatment, so that it can easily be transferred from one place to another. The permanence of its optical axis also renders it more convenient for long series of exact micrometrical measures, whilst its tube being closed at both ends renders its definition steadier and less liable to be injuriously affected by change of temperature than is the case with a reflector. On the other hand, the refractor is less easy to mount with perfect steadiness than the reflector, requires a much larger observatory, and is, except in the case of small instruments, not so easily handled and managed. Moreover, even in the finest telescopes, it is not perfectly achromatic, and lacks something of the sharpness of definition of bright objects possessed by reflectors. The great advantage possessed by the reflectors is their compactness, their focal length being little more than half that of refractors of corresponding aperture, so that they are far easier to mount steadily and to manage when mounted. They are also perfectly achromatic, and when in proper adjustment yield a wonderfully sharp and perfect image. Their great disadvantage is that they are more liable to get out of adjustment than refractors. This drawback, however, is not very serious, as after a little experience it is very easy to rapidly bring them back into satisfactory adjustment. They do not yield quite so steady an image, or quite so dark a field of view as the refractor, and as their optical axis is liable to be slightly changed in position by each readjustment, they are not quite so well suited for long series of measures with a micrometer. The greatest advantage of the reflectors, however, is their small cost. The optical part of a seven-inch refractor costs over a hundred pounds, whereas that of a reflector of corresponding size would not exceed a tenth of this sum. A completely mounted seven-inch refractor would cost about £350, whereas a reflector in every way as completely mounted, and twelve inches in aperture, would not cost £250.

It is probable that a refractor will be generally preferred when the aperture does not exceed seven or eight inches, and especially in the case where expense is no consideration, or where only occasional observations are to be made. For general physical observations of the heavens, however, and especially of the details visible on the surface of the moon and planets, for observations of their satellites, for searching for comets and new nebulæ, and in fact for all purposes where power is required, a reflector will generally be found preferable. For apertures exceeding eight inches the advantages of the reflectors become steadily on the increase.

Mountings.

The first thing to be considered in an astronomical telescope is the character of its mounting, for however excellent may be the optical part, it will never perform its work well unless it be properly mounted on a steady and convenient stand and be provided with all proper adjustments. A large telescope inadequately mounted will never be found so satisfactory as a smaller one properly mounted; nor indeed will it be found so powerful as the smaller, for the smaller telescope will perform to the utmost of its powers, whereas, owing to the want of a steady stand and proper fittings, it will be impracticable to call forth more than a portion of the full power of the larger instrument. The stand of an astronomical telescope may be of two forms—an *altazimuth* or an *equatorial*. In each case the instrument moves on two axes at right angles to one another, the difference being that in the altazimuth one of these axes is horizontal and the other vertical, so that the telescope moves in altitude or in azimuth; and in the equatorial one axis is placed parallel to the plane of the terrestrial equator, and the other parallel to the terrestrial axis of rotation, so that the instrument moves in declination and right ascension. The advantage of the latter form is obvious, for the telescope can be made to follow a star in its diurnal motion in the heavens by merely moving it around one axis or in a right ascension direction, whereas in the altazimuth it is necessary to move it around both axes in order to follow the apparent daily motion of the stars in the heavens.

The Altazimuth.

The only advantage possessed by this form of stand is its simplicity and consequent cheapness. In all other respects it is much inferior to the *equatorial*, so that its use is restricted to the smallest and cheapest instruments, or to those of very large dimensions, which are very costly to mount in a more complete manner. Small refractors from 2½ to 4 inches in aperture are commonly mounted on a tripod stand of this form; but they are scarcely adapted for astronomical purposes, being too small for observing the minuter features of the heavens, and too inadequately mounted for purposes of exact measurement. In consequence, as far as astronomical telescopes are concerned, this kind of mounting may be regarded as restricted to reflectors. A very convenient form of such mounting is shown in fig. 78. Astronomical telescopes mounted in this manner are now far from very expensive. A completely mounted reflector of from 6½ to 8½ inch aperture, with eye-pieces complete, can be purchased for from £25 to £50. With an instrument of this size good useful astronomical work can be done, especially in the study of the details visible on the surface of the moon and planets. The optical part of such a telescope—namely, the silvered glass speculum, the small plane silvered mirror, and the eye-pieces—can be purchased for rather less than one-half of the above sum; and in the hands of one used to tools can be mounted in a tolerably fair manner for about £5. As a rule however, it will be found far more satisfactory to purchase the telescope with its tube and fittings complete, and confine oneself to making the stand alone. Telescopes of the above form, with their tubes and fittings complete, would cost from £16 to £35.

The Equatorial.

In this form of mounting the telescope turns on two inclined axes placed at right angles to each other; one, termed the *polar axis*, being placed in the plane of the meridian and pointing to the pole of the heavens, so that it is parallel to the axis of the earth; the other termed the *declination axis*, lying parallel to the plane of the equator. Consequently, when the telescope is moved round its declination axis, it follows a great circle in the heavens, called "hour circles," on which are measured the declination of a star or other heavenly body; and when the telescope is moved round its polar axis, it moves in a circle parallel to the equator, and therefore in the same manner as is measured the right ascension of a body. Hence, by merely moving the telescope round its polar axis, it will completely follow a star in its daily motion in the heavens due to the rotation of the earth on its axis. If the instrument be fitted with a clock-work motion which makes the telescope turn once on its axis in a sidereal day, the telescope when once turned on a star or other point in the heavens will

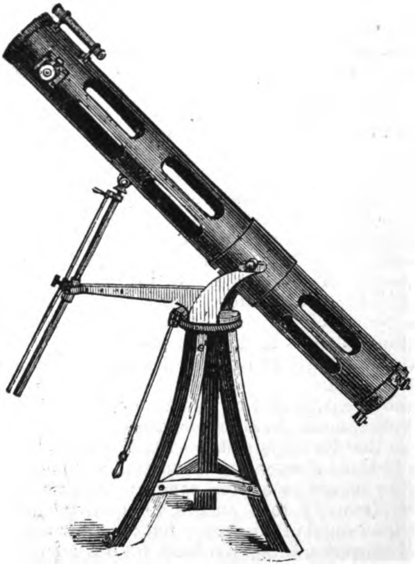


FIG. 78

always remain pointing exactly on the same star or spot. Moreover, by fitting properly adjusted graduated circles on the polar and declination axes, by inspecting these circles it is possible to tell the exact place in the heavens at which the telescope is pointing—that is, its exact right ascension and declination; and *vice versâ*, by turning the telescope until the circles show the proper right ascension and declination, the telescope may be directed to any particular point in the heavens. Thus, if the right ascension and declination of a star or other body be known, the telescope can be at once made to point exactly at it, by moving the telescope until the circles indicate the right figure.

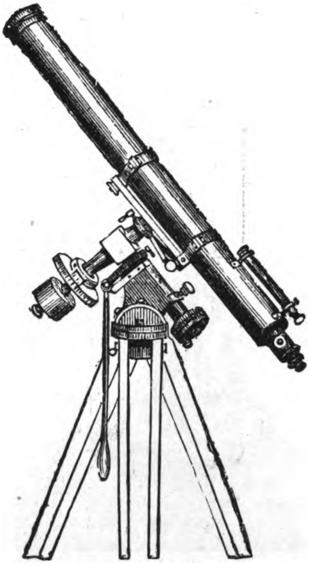


FIG. 79.

There are very considerable advantages, therefore, in this form of mounting. First, it is very easy to make the telescope follow a star for as long as may be desired, keeping it always in view; secondly the telescope can be at once turned with certainty on any star or other heavenly object, whether it be visible or not; and, thirdly, the right ascension and declination of any object visible in the telescope can be ascertained at once, and its identification secured without further trouble.

From what has been said, it is apparent that equatorial stands must be properly adjusted and placed in the plane of the meridian. This is easily done once and for all. As a rule, equatorial mountings are not meant to be moved after being once placed in position. Even, however, if a portable instrument be required, it is always possible to mark the position of any three points on the base of the stand, and then the mounting can always be restored to its proper position.

Equatorial mountings may be divided into two classes—*simple equatorials* and *complete equatorials*, only differing in the number and completeness of their accessory fittings.

In the first form the fittings and adjustments are made as simple as possible, the circles showing the declinations and right ascensions are not very finely graduated, generally only to 5′ of declination and 10″ of time, which is ample for the purpose of finding or identifying stars or planets. They are not provided with clock motion or with micrometers and other expensive accessories. In all other respects they have all the advantages of an equatorial mounting.

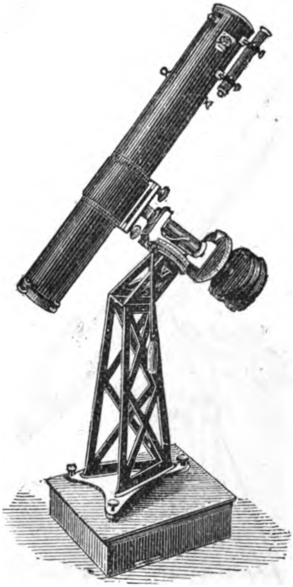


FIG. 80.

The Simple Equatorial.

Fig. 79 shows a very good form of such a mounting for a refractor of from four to six inches aperture. Larger instruments of this kind are rarely mounted except in the most complete manner, for the optical part of the instrument is so expensive that little is gained by a less costly mounting. These instruments can be regarded as portable, and carried indoors when not in use, it being easy to mark the exact place of the legs of the tripod when the stand is in its proper position, and so always restore it to its proper place when required for observation. Instead of a tripod stand, as shown, these instruments are often mounted on an iron pillar. They are then steadier and more permanent, but require to be sheltered by an observatory of some kind. Telescopes of this kind cost from £60 for a four-inch to about £200 for a six-inch. The stands alone cost from £25 for one suited for a four-inch telescope to £75 for one suited for a six-inch.

Fig. 80 shows a similar mounting for a reflector of from six to twelve inches aperture. These instruments, as a rule, are somewhat too heavy to be regarded as portable, but are easily sheltered under a low cover. They cost about £35 for a six-inch, about £70 for an eight-and-a-half-inch, and £100 for a twelve-inch. The stands by themselves cost about £15 to £35, according to their size.

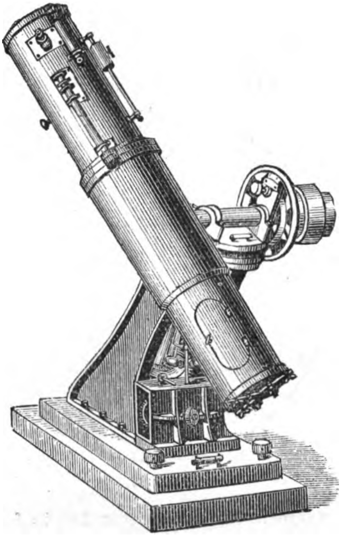


FIG. 81.

With these instruments, even the smallest, it is possible to do an enormous amount of thoroughly good and satisfactory astronomical work.

The principal feature distinguishing between the complete equatorial and the preceding class of instruments lies in their possessing a clock motion by which the polar axis is rotated so as to automatically follow the motion of a star in the heavens. This enables them to be fitted with micrometers and other expensive accessories. To obtain the full advantage of these mountings it is necessary that the instrument should be most carefully adjusted in position and maintained in adjustment. In consequence they are in no respect portable, and must be sheltered under an observatory. Refractors of this kind cost about £400 for a six-and-a-half-inch and some £1000 for a ten-inch; they need, moreover, somewhat expensive observatories. Reflectors of this kind are not so costly; but small instruments are not commonly mounted in this elaborate manner. One of ten inches aperture costs about £200, and one of fifteen inches aperture about £350. Fig. 81 shows a capital example of a mounting of this kind. Observatories for these instruments are not expensive, for they lie low and are very compact. Thus a ten-inch reflector requires an observatory only ten feet in diameter, and not necessarily more than eight feet high, whereas a refractor of similar size would require a dome fifteen feet in diameter and twenty feet high. The cost of such observatories would be from £40 to £70 for the reflector, and from £150 to £350 for the refractor.

The Complete Equatorial.

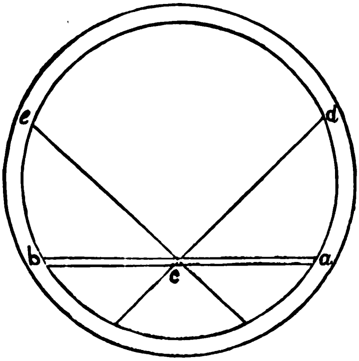


FIG. 82.

So much for the telescopes themselves; upon details of their construction and adjustment it would be out of place to touch here; particulars of this kind can be easily learnt from the little handbooks published at a nominal cost by nearly all the makers. Little more than expensive experience will be gained by any inexperienced persons trying to construct astronomical telescopes for themselves. Directions for such a purpose are useless.

Employing the Telescope.

Within the scope of the present pages it will be impracticable to give an account of the best methods of using a telescope; and indeed the only sure method of learning this is by actual experience, as all observers have their own preferences in this respect, often two selecting almost diametrically opposite ways of arriving at the same end. A few suggestions may be of use, however.

Reflectors perform best in the open air, or at least in a situation where they are merely sheltered from the wind. From their form, they are always mounted on low stands, and can easily be covered with a flat roof not more than six feet high. The kind of observatory most suited to them is therefore one with a roof which runs back from over at least one half of the observatory. Refractors necessarily are mounted on much higher stands, so that they require being covered by a domed or drum-shaped observatory roof. This roof may be made, however, with an opening or shutter only four feet wide, so that the instrument and observer are far better covered than when using a reflector.

Magnifying Powers.

The most suitable series of magnifying powers for a telescope are 15, 30, 45, 60 and 90 to the inch of aperture: thus for a telescope of six inches aperture a set of eyepieces magnifying 90, 180, 270, 360, and 540 is all that is required. A very low power eyepiece with a large field of view, and magnifying about 40, is useful for finding objects. The greater number of nebulæ, comets, and some few wide double stars, require the power of 15 to the inch of aperture; or if bright enough to bear it, as is the case with some comets and planetary nebulæ, the power of 45 to the inch may be used. For the sun, the power of 30 to the inch is the only one which will be of much service. Mercury and Venus in daylight will also require this power of 30. So will Saturn; but the satellites of Saturn will be best seen with the next higher power. Jupiter, Uranus, and Neptune will require the power of 45 to the inch, and at times Jupiter will bear even the next higher power. Most double stars will also be seen best with this eyepiece. Mars generally requires a power of 60 to the inch to show the markings well; it must also be used for Mercury and Venus when seen after sunset. The power of 90 is generally only of use for very close double stars. Sometimes, but very rarely, both Jupiter and Mars will bear this power. For the moon, a power of 45 will be found best for objects close to the terminator, but for those seen under high illumination, as when the moon approaches full, a power of 60 or even 90 should be used. Occasionally, in very steady air, a telescope will bear still higher powers than these, but it is rarely; and even when it does, no more can be seen with the higher power than can be made out with one of 90 to the inch. It is always a mistake to employ too large a magnifying power.

Micrometers.

For use with a micrometer, powers of 20 and 50 to the inch are the most useful, the former for general work, the latter for exceptional work, as measurement of very minute objects, close double stars, or the diameters of the planets. Ordinary micrometers can only be used with telescopes fitted with clock motion, unless the observer be exceptionally ingenious. A very convenient form of micrometer can be employed, however, for measuring other than very small distances. This is called the triangular micrometer, and is used for determining the difference between the right ascension and declination of two points; so that if the right ascension and declination of one be known, that of the other can be ascertained. It consists of an ordinary eyepiece with a large field, and magnifying about 15 to the inch of aperture, and is fitted with a system of four thin wires, arranged in the form of a triangle, as shown in fig. 82. Two of the wires are placed close together and parallel to each other, as shown at *a b*, and they are crossed by two others, *d c* and *e c*, which meet in a right angle at *c*, a point midway between the two wires *a b*. This micrometer is used as follows: the telescope is clamped in a position such that one of the points whose distance apart is to be measured moves slowly across the field of view parallel to and midway between the pair of wires *a b*; then the time, T, at which the one point passes the cross of wires at *c*, and time, T' $T,''$ at which the other crosses the wire, *d c* and *e c*, are noted in the same manner as the transit of a star is observed in a transit instrument. Then A, the difference in right ascension between the two points, will be equal to $\frac{1}{2}(T'' + T') - T$, and the difference, D, in declination is equal to $\frac{1}{2}(T'' - T') \times 15 \times$ cosine of the declination of the point whose position is known. From these the position angle and distance can easily be calculated. If either of the two points have a proper motion of their own, the amount of this motion must be subtracted or added to the above, according as it is in the same or opposite direction to the apparent motion of the heavens, but except in the case of the moon and sun, the amount of this motion is so small that it can generally be neglected. With this simple form of micrometer, distances can be measured with considerable accuracy. Any difference of right ascension can be measured, but that in declination is restricted to half a degree. Still greater differences in declination can of course be measured by the aid of some intermediate auxiliary star or point, by measuring in succession the difference in declination between the auxiliary point and the two objects on either side of it.

On Seeing.

Shortly after one has begun as a telescopic observer, a sense of disappointment is apt to set in, for everything seems so much smaller than was anticipated, and so little seems visible as compared with what others have seen and described. The observer has, in fact, commenced to find out that he has to educate his eyes. Even those who have had considerable practice in other branches of telescopic work, experience the same sensation when they first turn their attention to new features. Thus the most experienced observer of double stars finds himself quite at a loss when he commences to observe planetary details. The wisest use, therefore, that a beginner can make of his telescope for the first two years, is to turn it first on one body and then on another until he can see what has already been seen by others with similar objects. A work like the "Celestial Objects" of the Rev. T. W. Webb forms a capital directory for this purpose. He thus learns how best to use his telescope, he gains experience in interpreting what he sees and in what to look for, and, above all, he educates his eye. Having at the end of this period learnt what others have already done, he is then better qualified to try and do something for himself. It should always be remembered that very little has ever been done in science by any one who was not familiar with the labours of his predecessors in the same field.

In employing one's telescope, the first thing to be remembered is, that if anything be worth watching it is worth noting. Make a note of everything done and seen. Every observation should be accompanied by full details, and the day and hour, instrument and power employed, and state of the weather, should be all stated. Further, if anything that is seen requires a description, in its turn the description should be accompanied by a sketch. It does not matter how rough and imperfect the sketch may be at first: before very long, certainly long before the two years of preliminary work be over, the knack of making tolerably faithful sketches will have been acquired. The sketch need not be artistically finished, but let it be as faithful as possible. In drawing any object first carefully put down the exact relative positions and dimensions of the main features, and then fill in the minor features. It is only in this manner that you can be sure that every part will be represented in its proper proportions. Where differences in tint or brightness have to be delineated, it will often be found advantageous to give each a kind of numerical value, or else carefully express their difference in words, and then insert them afterwards. Attempts to delineate them at the telescope, by mere shading, often lead to serious exaggeration.

On Recording.

The next point to be remembered is that, wherever possible, dimensions should be given. Thus, if a spot be seen on the sun or on a planet, its size should be given; if a star, its magnitude should be estimated, and so on. Further, in most cases the position should be noted—that is, its distance from two or more points whose position is known. This more especially refers to objects seen for the first time. These distances can generally be estimated by the eye if they are small, and if large they can be easily measured by the aid of the triangular micrometer already described.

Most observations, especially those involving measurement of distances and positions, require some auxiliary calculation to reduce them to the standard form employed by other astronomers: this reduction should be carefully done soon after the observation; and none should be published unless this has been done. Drawings of the aspect of planets, or different regions on the moon, should be accompanied by all information of this kind—as for example the phase of the planet, the libration of the moon, etc. More especially, every observation should be carefully dated; it is valueless without.

Instructions for making measures with ordinary micrometers, determining the true time, or the error of the clock, and for reducing the observations when made, will be found in most works on practical astronomy, as Loomis's "Practical Astronomy," which is a sort of standard inexpensive work.

CHAPTER XXVI.

WORK FOR THE TELESCOPE.

The Sun—The Moon—The Planets—Comets—Double Stars—Nebulæ.

AFTER mastering the preliminary difficulties of practical observation, and after having become familiar with the more striking beauties of the heavens, the time at length arrives when the observer becomes weary of purposeless labour and longs to direct his efforts towards making some serviceable contribution towards the advancement of the great science of astronomy. At first this does not seem difficult, for there seem to be great fields for exploration on every side; but when he proceeds to select some definite line of work, he finds all alike seem to elude him, for he does not know how to set to work. Though innumerable inchoate ideas seem to float around him, they all prove intangible when he seeks to grasp them, and from one and all alike he fails to elicit a single definite idea for working out to a successful end. Therefore, after having repeatedly failed to find anything by which he can realise his ideas of contributing to the advancement of astronomy, he is apt in sheer disappointment to think the task is beyond his power, and so gradually neglects his instrument for want of a definite object, and slowly loses his interest in the practical work he has undertaken. In this manner, many of those who have most enthusiastically taken to telescopic work have been lost to astronomy.

Openings for Useful Work.

With the view of suggesting useful work for those who do not know in what direction to direct their labours, it is proposed to briefly indicate some of the different lines of special work which lie open for investigation in the different branches of practical work, and any of which might be taken up and carried out to a successful termination by a patient and careful observer, in possession of any telescope of moderate power.

THE SUN.—This luminary does not offer much opening for merely telescopic work, and the little that there is to be done has now been undertaken by several of the permanent observatories. The more special departments of solar work, such as the photographic and spectroscopic branches, require as a rule special apparatus not generally found in the possession of the ordinary observer. It would be of little avail, therefore, to particularise the opening for such work as remains to be done in connection with the sun.

INTRA-MERCURIAL PLANETS.—The search for these bodies affords an opening for useful astronomical work, and one not unlikely to yield brilliant results. A watch should be kept on the sun, using high powers for minute circular dark spots, probably not more than 2″ in diameter. Should such a body be found, it should be carefully examined, to see if it be in moderately quick motion. Such a body would cross the sun in from two to six hours. Its position could be determined by timing the interval between the transit of the solar limb and the suspected body. If, however, such bodies exist, it is more likely that they would be found by systematically searching in the neighbourhood of the sun. Fine, clear, cloudless days should be taken—days when the sky is seen of a clear deep blue; and some time in the forenoon chosen, say between 9 a.m. and 12 a.m., as there is then little mist. A very long dew-cap should be fitted to the telescope. It is easy to construct one, in the shape of a tubular framework made out of long slender rods of wood, braced together at intervals by cross-pieces and covered with some thin dark material such as *alpaca*; such a dew-cap can be made ten feet long, and yet only three or four pounds in weight. If the telescope be fitted with such an appendage, it is easy to shut off nearly all the glare from the sun, and at ease carefully scrutinize its neighbourhood. Stars of the third magnitude can easily be seen on fine days in such a manner, when quite close to the sun. In the search for intra-mercurial planets, a region about twenty degrees long and three degrees wide on either side of the sun should be carefully swept over, and any star seen noted. Its place can easily be found by determining the interval between the transit of the solar limb and the suspected body over a wire in the eyepiece. Practice should first be gained by searching in this manner for Venus and Mercury when near the sun, it being easy to find out their exact position, so as to know where to look for them, should the previous search have failed to reveal them. Later, Mars should be looked for in the same manner. During this work it is not at all unlikely one or more comets may be detected on their approach towards perihelion, and so important extra discoveries reward the patience of the observer.

MERCURY.—This planet is not one of those which afford much scope for telescopic work. Yet a good deal might be learnt from a long series of observations of the details of its surface, especially from midday observations with the aid of a long solar dark cap to the object glass. With Mercury, as with several others of the planets, as the observations are made under somewhat exceptional conditions until the eye has gained considerable experience and has become used to the novel circumstances, very little will repay the trouble taken; but when the eye has been properly educated it will be found that there is a great deal more detail to be clearly seen than would at first be thought possible, or than can be seen by those inexperienced in this special kind of observation. When Mercury is near the sun, particular attention should be devoted to observing the irregularities in the border between the illuminated and unilluminated portions of the disc, and to seeing whether the horns or cusps of the illuminated limb are prolonged beyond the semicircle. If so, the amount of this prolongation should be noted, so as to determine the density of the atmosphere of the planet.

VENUS.—The markings of this planet should be studied in daylight in the same manner as those of Mercury. If any spots be seen, their motion should be watched in order to determine the position of the equator and axis of rotation of the planet. The prolongation of the cusps of Venus which is visible whenever the planet is near inferior conjunction should be measured, so as to obtain a new determination of the density of its atmosphere (see *Monthly Notices of Roy. Ast. Soc.*, lxxxvii.). When Venus is between inferior conjunction and the epoch of greatest brilliancy, opportunity might be taken for searching for minute satellites. This of course must be done after sunset. Every minute star within a degree of Venus should be carefully mapped down, and then after allowing an hour to pass re-mapped to see if any have moved. As the position of the equator of the planet is not well known, this examination should be extended all round the planet. After some experience has been gained it will not be found difficult to map down in this way all stars brighter than the 11th standard magnitude, usually some thirty or forty in number. Another subject which might repay examination is the supposed phosphorescence of the dark side of Venus, by which it is seen as it were as a grey body against the darker sky.

THE MOON.—A great field for useful work lies open to observers in connection with the moon—too great a field, in fact, for more than a small portion to be particularised here. For others reference must be made to the *Selenographical Journal*, the organ of the Selenographical Society, or to some standard work on the moon. With the aid of a simple micrometer (described in the *Selenographical Journal*, vols. i. and iii.), it is possible to continue and extend the determining of the position of the principal points on the lunar surface—an important work which much requires completion. In the same manner measurements might be made of the height of the different irregularities in the limb, and the position determined of the principal ones—a work which would be an important contribution towards perfecting the lunar theory. Another important question, the amount and variations in the irradiation at the border of a bright object such as the limbs of the moon and planets, could be most easily studied by measurements of the distance of the lunar limb from some bright point on its surface near the edge. Again, much might be learnt by an examination of the supposed twilight at the cusps of the moon, seen by Schröter, Gruithuisen, and others, and regarded by them as indicating the existence of an atmosphere. Other work of a different kind consists in observing the variations in tint of different portions of the surface of the moon, and in the position of some of the bright streaks or radiations from some of the great formations, such as Tycho.

MARS.—The principal work to be done on this planet seems to be the re-determination of the position of its equator and axis of rotation by measuring the position of some well-marked point on its surface, such as the *Kaiser Sea*. This, however, would require a long series of measures with the aid of a powerful, well-appointed telescope. A search for exterior satellites might also repay the labour. Here, as the plane of the equator of Mars is well known, it would only be necessary to examine all the stars in a belt on each side of the planet—say, a belt extending for a degree on either side and a tenth of a degree in width. After experience had been gained, every star, down to the 13th magnitude at least, might be mapped in an hour;

they would seldom exceed thirty in number. Then from two to four hours afterwards they should be again examined, to see if any had moved along with the planet, and so any satellite be detected. It would be useless looking within five minutes of the planet, on account of the glare.

THE MINOR PLANETS.—It would be worth while to carefully examine the region around one or more of the larger of these bodies, on the chance of discovering a satellite: success would be an important contribution to astronomy. The search might extend to all stars within half a degree, and down to stars of the 12th and 13th magnitude, perhaps some fifty in number; though it might be advantageous to confine oneself to a zone on either side of the orbit of the minor planet—a zone say a tenth of a degree wide. Useful work might also be accomplished by selecting a dozen of the smaller of these bodies, and on a dozen days at the opposition of each carefully determine their position with regard to some neighbouring bright star. To render this work complete it would be necessary to properly reduce all these observations, and determine the errors of the ephemeris. This work would form a sound, useful contribution to science; for many of the smaller of these bodies, being too faint to be easily observed in ordinary meridian instruments, are often not observed at all, so that they run a chance of being lost again. At least one has thus been lost and cannot now be found. This work, like all other astronomical work leading to exact results, possesses a charm which would not be anticipated by any one unfamiliar with it: the calculations involved are neither difficult nor laborious, and they may be made to lead to results of general interest and importance, by observing the distance of the planet from neighbouring stars, first when it is near the eastern and secondly when near the western horizon. Opportunity might be taken of favourable opposition for determining the solar parallax by the method already described. The search for new minor planets has ceased to be a work of much advantage.

JUPITER.—To those with powerful telescopes the principal work to be done in connection with this planet is to watch the changes taking place in the details of its belts. This is practically beyond any telescope of less than twelve inches aperture; much may be seen with far less powerful means, but not with sufficient completeness to render it likely that any discoveries will be made. The determination of the time of the rotation of the spots which are from time to time visible is a work which may well repay the labour bestowed on it. A search for a fifth satellite, lying about as far away again as the fourth satellite, but very much fainter, might lead to an unexpected discovery. Nor is it unlikely that another satellite may lie between the first satellite and the planet; but it is very faint, not brighter than the 10th magnitude, and so would not be readily discovered on account of the proximity of Jupiter, and consequent glare. The timing of the duration of the eclipse of the third and fourth satellites, when both the disappearance and reappearance can be seen, would throw much light on the question of the dimensions of Jupiter's atmosphere.

SATURN.—There is not much work to be done on this planet except by those provided with extra powerful or well equipped instruments. The observation of the conjunction of the two inner satellites of Saturn with the ends of the ring can be made with advantage, as furnishing data for improving the theory of their motion. Search might also be made with advantage for minute satellites in the great gap between Titan and Iapetus, but the work would be laborious. Observation could also be made of the ring with the view of determining the time of its rotation from any small spot seen upon it. There is little opening for anything else.

Uranus and *Neptune.*—These two planets are so distant, and consequently so minute in apparent dimensions, that little systematic work can be done on them except with very large instruments, say of twelve or fifteen inches aperture. Careful search with smaller instruments might very likely lead to the discovery of new satellites, especially in the case of Neptune.

Ultra-Neptunian Planets.—These suspected bodies and the method of searching for them have been already referred to. It is not unlikely that such a search might be successful, but it would certainly be laborious and long.

COMETS.—The search for comets, especially near the sun, affords one of the most useful departments of telescopic work, though one requiring a considerable amount of previous experience, or every small nebula may be taken for a comet. After a time, however, it is not difficult to learn to recognise at sight all the nebulæ in any given portion of the heavens, and then the search for new comets becomes facilitated. A portion of the heavens covering a space of about five degrees in right ascension and thirty degrees in declination should be selected, and every nebula in it examined until they become familiar to the eye—at first employing Sir J. Herschel's reference catalogue of nebulæ for identifying each. If this region be carefully swept over every clear night, it would ensure the detection of any comet crossing it. By selecting three such portions at intervals of about eight hours of right ascension, one if not two would always be suitable for examination on every night. At present the search for comets is not systematically carried out, and probably not one in ten of the comets which come to perihelion in the course of the year are detected. When discovered its apparent place should be fixed by reference to neighbouring stars, until one or more large observatories take up its observation. The computation of the approximate orbit of a comet, from three or more observations, is by no means a difficult work, requiring only a knowledge of the elements of spherical trigonometry. the observations of the details of the physical constitution of a comet cannot well be carried on except with very powerful optical means, and even then an observer must have a special knowledge of mathematical physics and chemistry before he can properly interpret the meaning of what he sees. It must always be remembered that it is useless to accumulate accounts of what is seen or thought to be seen, unless one can interpret in some degree the meaning of what is seen. No one else can properly do this from your account, and no one really competent to do so is likely to waste time in the attempt.

DOUBLE STARS.—The observation of these bodies usually possesses a considerable fascination for most observers, who naturally like to make their telescopes do all that has been done by others with similar instruments. This, however, is in no way a contribution to science, though undoubtedly a good training for the eye. Even the mere measurement of the distance and position angle of a few doubles is of little use to science. On the other hand, the selection of a few binary double stars, and their repeated measurement with the view of determining the orbit of the system, is a work of real utility. In such a case the observer should not rest content until he has mastered the art of calculating the orbits from his own observations.

STELLAR PARALLAX.—This is as a rule only within the reach of those observers with very completely mounted instruments. But much may be done by searching for stars which seem to have a large parallax. Likely stars—and binary double stars are the most likely—should have their position with regard to some small neighbouring star most carefully determined on several days at the two epochs in the year; once when they are on the meridian at about 8 p.m., and the other when on the meridian at about 4 a.m. If the mean of the distances at each epoch, when properly corrected, differ by half a second of arc, a measurable parallax may be suspected, and of course can be confirmed by repeating the measures. In any case the observation should be extended over several years, in order to make sure that the results of each year confirm one another.

NEBULÆ.—These present little, if any, opening for useful work, except to those who are skilful physicists, and possess their own special appliances. The mere discovery of nebulæ is no longer of any importance. The only work of any practical utility within the powers of the ordinary observer is the detection of the proper motion or parallax of some planetary nebula. The former could only be done by the work of a number of years; the latter might be carried out in the same manner as for detecting parallax in stars.

General.

In the preceding a number of lines of work have been briefly indicated. The details necessary to carry them out have of necessity been omitted. But if any observer, who had duly qualified himself for the work, were willing to carry out any specified line of investigation, there are few more experienced astronomers who would nct be willing to afford him the benefit of their advice as to the best means of carrying our his intention; and choice would naturally be made of one who had worked in the same field.

One thing is most important: it is useless to make and publish a mass of unreduced observations. No one can reduce these observations so well as their author, and no one will ever take the trouble to attempt it. Unreduced observations are practically wasted labour. The purchase of a work on practical astronomy will furnish all the information as to how the observations should be reduced, unless it be in an unusual line of work, and then it is only necessary to consult the labours of his predecessors to learn how to reduce these. In no case is it likely to demand more than an acquaintance with the rudiments of algebra and trigonometry; and a sufficient knowledge of these could be gained in a month. Observations reduced and compared with any theory or hypothesis are of value; unreduced they are valueless. And with these important words we bring these pages to a close.

THE CHEAPEST STANDARD BOOKS PUBLISHED.

Price 1/-

WARD & LOCK'S SHILLING LIBRARY OF

FAMOUS BOOKS FOR ALL TIME.

Neatly and strongly bound in cloth, price *1s.* each.

Under the above title, the publishers are issuing, in a popular form, with the appropriate fitting out of **clear print, good paper, and strong and neat cloth binding,** *a collection of such books as are best adapted for general reading, and have survived the generation in which and for which they were written—such books as the general verdict has pronounced to be "Not of an age but for all time." The purpose has been, and is, to include in this series books of the most various kinds, and addressed to the most different ages; to embrace, in the fullest manner, the whole domain of what is called "General Reading," in order that the series may form in itself a course of reading for the household, in which the wants and capacities of the various members, however wide may be the difference in their ages and tastes, shall be duly considered and catered for.*

The Volumes now ready are as follows:—

1 **Cobbett's Advice to Young Men.**
2 **Grimm's Fairy Tales,** and other Popular Stories.
3 **Evenings at Home.** By Dr. AIKEN and Mrs. BARBAULD.
4 **McCulloch's Principles of Political Economy.**
5 **Macaulay's Reviews and Essays, &c.** 1st Series.
6 **Macaulay's Reviews and Essays, &c.** 2nd Series.
7 **Macaulay's Reviews and Essays, &c.** 3rd Series.
8 **Sydney Smith's Essays.** 1st Series.
9 **Sydney Smith's Essays.** 2nd Series.
10 **Bacon's Proficience & Advancement of Learning, &c.**
11 **Bacon's New Atlantis, Essays, &c.**
12 **Josephus: Antiquities of the Jews.** With Notes.
13 **Josephus: The Wars of the Jews.** With Notes.
14 **Butler's Analogy of Religion.** With Notes, &c.
15 **Paley's Evidences of Christianity.** Life, Notes, &c.
16 **Bunyan's Pilgrim's Progress.** Memoir of Author.
17 **Robinson Crusoe.** By DANIEL DE FOE. With Memoir.
18 **Sandford and Merton.** By THOMAS DAY. Illustrated.
19 **Foster's Decision of Character.** With Memoir.
20 **Hufeland's Art of Prolonging Life.**
21 **Todd's Student's Manual.** By Rev. JOHN TODD.
22 **Paley's Natural Theology.** With Notes, &c.
23 **Paley's Horæ Paulinæ.** With Notes, &c.

Bound uniform with the above:—

50 **Beeton's Art of Public Speaking.**
51 **Beeton's Curiosities of Orators and Oratory.**
52 **Beeton's England's Orators.**
53 **Beeton's Great Speakers and Great Speeches.**
54 **Masters in History.** By the Rev. P. ANTON.
55 **Great Novelists.** By J. C. WATT.
56 **Life of Thomas Carlyle.** By H. J. NICOLL.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT THREE SHILLINGS & SIXPENCE.

Price

3/6

THE HOME TREASURE LIBRARY.

With Illustrations, cloth gilt, gilt edges, *3s. 6d.* each.

1 **Shiloh.** By Mrs. W. M. L. JAY. Coloured Illustrations.
2 **The Prince of the House of David.** Coloured Illusts.
3 **Miss Edgeworth's Moral Tales.** Coloured Illustrations.
4 **Miss Edgeworth's Popular Tales.** Coloured Illusts.
5 **Throne of David.** By Rev. J. H. INGRAHAM. Illusts.
6 **Pillar of Fire.** By Rev. J. H. INGRAHAM. Illustrated.
7 **Anna Lee.** By T. S. ARTHUR. Illustrated.
8 **Wide, Wide World.** By E. WETHERELL. Col. Illusts.
9 **Queechy.** By the same. Coloured Illustrations.
10 **Melbourne House.** By the same. Coloured Illustrations.
11 **Sceptres and Crowns.** By the same. Coloured Illusts.
12 **Fairchild Family.** By Mrs. SHERWOOD. Col. Illusts.
13 **Stepping Heavenward.** E. PRENTISS. Col. Illustrations.
14 **Mabel Vaughan.** By Miss CUMMING. Coloured Illusts.
15 **Dunallan.** By GRACE KENNEDY. Coloured Illustrations.
16 **Father Clement.** By the same. Coloured Illustrations.
17 **Holden with the Cords.** By Mrs. JAY. Col. Illusts.
18 **Uncle Tom's Cabin.** Coloured and other Illustrations.
19 **Barriers Burned Away.** By E. P. ROE. Col. Illusts.
20 **Little Women and Good Wives.** By Miss ALCOTT.
21 **From Jest to Earnest.** By E. P. ROE. Col. Illusts.
22 **Near to Nature's Heart.** By E. P. ROE. Col. Illusts.
23 **Opening a Chestnut Burr.** By E. P. ROE. Col. Illusts.
24 **What Can She Do?** By E. P. ROE. Coloured Illusts.
25 **The Old Helmet.** By E. WETHERELL. Coloured Illusts.
26 **Daisy.** By the same. With Coloured Illustrations.
27 **A Knight of the Nineteenth Century.** Col. Illusts.
28 **Woman our Angel.** By A. S. ROE. Coloured Illusts.
29 **The Lamplighter.** By Miss CUMMING. Coloured Illusts.
30 **A Face Illumined.** By E. P. Roe. Coloured Illusts.
31 **The Story of Stories.** By Mrs. LEATHLEY. Illustrated.
32 **A Day of Fate.** By E. P. ROE. With Frontispiece.
33 **Odd or Even.** By Mrs. WHITNEY. Illustrated.
34 **Without a Home.** By E. P. ROE. With Frontispiece.
35 **Ida May.** By MARY LANGDON. Coloured Illustrations.
36 **Helen.** By MARIA EDGEWORTH. Illustrated.
37 **Our Helen.** By SOPHIE MAY. With Frontispiece.
38 **His Sombre Rival.** By E. P. ROE. With Frontispiece.
39 **An Original Belle.** By E. P. ROE. With Frontispiece.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT THREE SHILLINGS & SIXPENCE.

Price

THE GOOD WORTH LIBRARY.

In the Good Worth Library *no works have been admitted in which the three requisites for good worth in a book,—namely, the promotion of knowledge, the furtherance of wisdom, and the charm of amusement—are not combined.*

Crown 8vo, cloth gilt, *3s. 6d.* each.

3/6

1 **Bunyan's Pilgrim's Progress.** With Memoir of the Author by H. W. Dulcken, Ph.D., and **100 Illustrations.**
2 **The Swiss Family Robinson.** Translated by Henry Frith. With **Coloured Plates and upwards of 200 Engravings.**
3 **Hans Andersen's Stories for the Young. Illustrated.**
4 **Hans Andersen's Popular Tales for Children. Do.**
5 **Ann and Jane Taylor's Poetry for Children.** Original Poems, Hymns for Infant Minds, Rhymes for the Nursery. **Illust.**
7 **Fifty Celebrated Women:** Their Virtues and Failings, and the Lessons of their Lives. With many **Engravings.**
8 **Fifty Celebrated Men:** Their Lives and Trials, and the Deeds that made them Famous. With many **Engravings.**
9 **Robinson Crusoe.** Memoir and many **Engravings.**
10 **The Wonders of the World.** With 123 **Engravings.**
11 **Evenings at Home;** or, The Juvenile Budget Opened. By Mrs. Barbauld and Dr. Aiken. With many **Engravings.**
12 **The Gentlemen Adventurers;** or, Antony Waymouth. By W. H. G. Kingston. With full-page **Engravings.**
13 **Sandford and Merton.** With **100 Engravings.**
14 **The Boy's Own Sea Stories.** Full-page **Engravings.**
16 **Great Inventors:** The Sources of their Usefulness, and the Results of their Efforts. With **109 Engravings.**
17 **The Marvels of Nature;** or, Outlines of Creation. With **400 Engravings** by Dalziel Brothers.
18 **The Boy's Own Book of Manufactures and Industries** of the World. With **365 Engravings** by Dalziel Brothers.
19 **Famous Boys,** and How they Became Famous Men. **Illust.**
20 **Triumphs of Perseverance and Enterprise. Illust.**
21 **The Crusades and Crusaders:** The Story of the Struggle for the Holy Sepulchre. By J. G. Edgar. **Illustrated.**
22 **The Merchant's Clerk;** or, Mark Wilton. By Rev. C. B. Tayler, M.A. With full-page and other **Engravings.**
23 **The Young Marooners;** or, The Adventures of Robert and Harold on the Florida Coast. With many **Engravings.**
24 **Holiday House.** By Catherine Sinclair. **Illustrated.**
25 **The Boy's Book of Modern Travel. Illustrated.**
26 **Mary Bunyan,** the Blind Daughter of John Bunyan. By Sallie Rochester Ford. With full-page **Engravings.**
27 **The Scottish Chiefs.** By Jane Porter. **Illustrated.**
30 **Life Thoughts.** By Henry Ward Beecher. With Red Border Lines.
31 **The Christian Life:** Bible Helps and Counsels.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT THREE SHILLINGS & SIXPENCE.

Price
3/6

THE GOOD WORTH LIBRARY—*continued.*

32 **The Perfect Life.** By WILLIAM E. CHANNING.
33 **Sacred Heroes and Martyrs.** By J. T. HEADLEY.
34 **Religion and Science.** By JOSEPH LE CONTE.
35 **Getting On in the World**; or, Hints on Success in Life. The Two Series Complete in One Volume. By W. MATHEWS, LL.D.
36 **Grimm's Fairy Tales**, &c. Profusely **Illustrated.**
37 **Boy's Handy Book of Games and Sports. Illustrated:**
38 **Boy's Handy Book of Natural History. Illustrated.**
39 **Gutenburg**; or, The World's Benefactor. **Illustrated.**
40 **Uncle Mark's Money**; or, More Ways than One.
41 **The Arabian Nights' Entertainments. Illustrated.**
43 **Lion Hunting. Illustrated** by GUSTAVE DORE, &c.
44 **The Backwoodsman.** By Sir C. F. L. WRAXALL, Bart.
45 **Hunting Adventures in Forest and Field. Illust.**
46 **Famous People and Famous Places. Portraits, &c.**
47 **Reedyford**; or, Creed and Character. Rev. S. HOCKING.
48 **Children at Jerusalem.** By Mrs. HOLMAN HUNT. With Frontispiece by the Author. Also in fancy wrapper, price ***1s.***
49 **Cheerful Homes**; How to Get and Keep Them. By Dr. KIRTON, Author of "Buy your Own Cherries." **Illustrated.**
50 **Heaven's Messengers**: A Series of Stirring Addresses.
51 **The Freedom of Faith.** By Rev. T. T. MUNGER.
52 **On the Threshold**: Counsel to Young Men. Ditto.
53 **Treasures of Truth for Busy Lives.** A Book of Good Counsel for Young and Old.
54 **The Little Ragamuffins of Outcast London.** By the Author of "A Night in a Workhouse," &c. **Illustrated.**
55 **From Log Cabin to White House**: The Story of the Life of President Garfield. By W. M. THAYER. **Illustrated.**
56 **Occident.** By Rev. JOSEPH COOK, of Boston.
57 **England's Hero and Christian Soldier**: The Life of General GORDON. With **Maps** and numerous **Engravings.**
58 **Beeton's Complete Orator.** A Complete Guide to Public Speaking, with Examples and Anecdotes.
59 **Wild Sports of the World.** By JAMES GREENWOOD. Profusely **Illustrated.**
60 **Brave British Soldiers and the Victoria Cross.** With numerous full-page **Engravings.**
61 **Silas Horner's Adventures**; or, The Captive Conjurors. By JAMES GREENWOOD. Profusely **Illustrated.**
62 **The New Evenings at Home**; or, Chats about Knowledge. By the Author of "Picciola." **Illustrated.**
63 **History of Napoleon Bonaparte. Illustrated.**

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT THREE SHILLINGS & SIXPENCE.

Price

THE FAMILY CIRCLE LIBRARY.

A Series of Popular Books, specially designed for Gifts and Rewards, and for Family Reading and Reference.

Fully Illustrated and handsomely bound, cloth gilt, gilt edges, ***3s. 6d.*** each.

3/6

1 **Margaret Catchpole (The History of).** By Rev. R. Cobbold. With **Coloured Plates and other Illustrations.**

2 **Beatrice.** By Catherine Sinclair. With **Col. Plates.**

3 **Amy and Hester;** or, The Long Holidays. By H. A. Ford. With **Coloured Frontispiece and many Engravings.**

4 **Wonders and Beauties of the Year.** Descriptions of the Wild Flowers. Birds, and Insects of the Mouths. **Coloured Frontispiece and Engravings.**

6 **Nature's Gifts,** and How we Use them. By George Dodd. With **Coloured Frontispiece and other Illustrations.**

7 **Modern Society.** By Catherine Sinclair. **Coloured and other Illustrations.**

8 **Herbert Lovell;** or, Handsome He who Handsome Does. By Rev. F. W. B. Bouverie. With **Coloured and other Illustrations.**

9 **The Sailor Hero;** or, The Frigate and the Lugger. By Capt. Armstrong. With full-page **Illustrations.**

10 **Cruise of the "Daring."** By Capt. Armstrong.

11 **Life's Contrasts;** or, The Four Homes. By Mrs. Gother Mann. With **Coloured Frontispiece and other Illustrations.**

12 **Popular Preachers of the Ancient Church:** Their Lives and their Works. By Rev. W. Wilson. With **Illustrations.**

13 **Edwin and Mary;** or, The Mother's Cabinet. With **Coloured Frontispiece and other Illustrations.**

14 **The Book of Children's Hymns and Rhymes.** With **Coloured Frontispiece and many Engravings.**

15 **Looking Heavenward:** A Series of Tales and Sketches for the Young. **Coloured Frontispiece and many Engravings.**

16 **Character and Culture.** By the Bishop of Durham, Canon Dale, &c. With Passages Selected from the Works of Eminent Divines.

17 **Pilgrims Heavenward:** Essays of Counsel and Encouragement for the Christian Life. **With Coloured Frontispiece.**

18 **Preachers and Preaching,** in Ancient and Modern Times. By the Rev. Henry Christmas. **With Portraits.**

19 **Julamerk.** By Mrs. Webb. **Coloured and other Illustrations.**

WARD, LOCK & CO., London, Melbourne, and New York.

Price 3/6

THE FAMILY CIRCLE LIBRARY—*continued.*

20 **Fern Leaves from Fanny's Portfolio.** First and Second Series Complete. With numerous **Illustrations.**

21 **Orange Blossoms.** By T. S. ARTHUR. With numerous **Illustrations.**

22 **The Martyrs of Carthage**; or, The Christian Converts. A Tale of the Times of Old. With numerous **Illustrations.**

23 **Modern Accomplishments**; or, The March of Intellect. By CATHERINE SINCLAIR. With **Coloured Plates.**

26 **Poe's Tales of Mystery, Imagination, and Humour.** By EDGAR ALLAN POE. With numerous **Illustrations.**

28 **Beeton's Book of Birds**: Showing how to Rear and Manage them in Sickness and in Health. With **Coloured Plates** by HARRISON WEIR, and over **100 Engravings.**

29 **Beeton's Book of Poultry and Domestic Animals**: How to Rear and Manage them in Sickness and in Health. With **Coloured Plates** by HARRISON WEIR, and over **100 Engravings.**

31 **Journeys through London**; or, Bye-ways of the Modern Babylon. By JAMES GREENWOOD, Author of "A Night in a Workhouse," &c. With **12 double-page Engravings.**

33 **Adventures of Captain Hatteras.** Containing "The English at the North Pole," and "The Ice Desert." By JULES VERNE. With **Coloured Plates.**

34 **Twenty Thousand Leagues Under the Sea.** First and Second Series Complete. By JULES VERNE. With **Coloured Plates.**

35 **The Wonderful Travels.** Containing "Journey into the Interior of the Earth," and "Five Weeks in a Balloon." By JULES VERNE. With **Coloured Plates.**

36 **The Moon Voyage.** Containing "From the Earth to the Moon," and "Round the Moon." By JULES VERNE. With **Coloured Plates.**

37 **The Autobiography of a Merchant**; or, The Story of James Meetwell.

38 **South and West Australia.** By ANTHONY TROLLOPE. With Maps.

39 **New South Wales and Queensland, Victoria and** Tasmania. By ANTHONY TROLLOPE. With Maps.

40 **William Ewart Gladstone**: A Political and Literary Biography. By G. R. EMERSON. With Portrait.

41 **The Art of Modern Conjuring, Magic, and Illusions.** A Practical Treatise on the Art of Parlour and Stage Magic, Illusions, Spiritualism, Ventriloquism, Thought-Reading, Mesmerism, &c. By Prof. HENRI GARENNE. With **162 Explanatory Engravings.**

GIFT BOOKS AT HALF-A-CROWN.

Price

THE GOOD TONE LIBRARY.

The volumes included under this head are those really High-class Works which are most calculated to elevate the mind and give a high tone to the character. The names of the Authors are in themselves sufficient evidence of careful selection.

Post 8vo, elegantly bound, cloth gilt, price *2s. 6d.*

2,6

1 **The Prince of the House of David.** By Rev. J. H. Ingraham. With Coloured Frontispiece.
2 **The Wide, Wide World.** By Elizabeth Wetherell. With Coloured Frontispiece.
3 **Queechy.** By Elizabeth Wetherell. With Coloured Frontispiece.
4 **Melbourne House.** By Elizabeth Wetherell. With Coloured Frontispiece.
5 **Uncle Tom's Cabin.** By Mrs. H. B. Stowe. With Sketch of the Life of Rev. Josiah Henson. Coloured Illustrations.
6 **Stepping Heavenward.** By Mrs. E. Prentiss. With Coloured Frontispiece.
7 **History of the Fairchild Family.** By Mrs. Sherwood. With Coloured Frontispiece.
8 **Anna Lee:** the Maiden, the Wife, and the Mother. By T. S. Arthur. With Illustrations.
9 **The Flower of the Family.** By E. Prentiss. With Coloured Frontispiece.
10 **From Jest to Earnest.** By E. P. Roe. With Coloured Frontispiece.
11 **The Throne of David.** By Rev. J. H. Ingraham. Illustrated.
12 **The Pillar of Fire.** By Rev. J. H. Ingraham. Illustrated.
13 **Shiloh;** or, Without and Within. By Mrs. W. M. L. Jay. With Coloured Frontispiece.
14 **Holiday House.** By Catherine Sinclair. With Coloured Frontispiece.
15 **Little Women.** By Louisa M. Alcott. With Coloured Frontispiece.
16 **Good Wives.** Sequel to, and by the Author of, "Little Women." With Coloured Frontispiece.
17 **The Lamplighter.** By Miss Cumming. With Coloured Frontispiece.
18 **The Old Helmet.** By the Author of "Queechy," &c. With Coloured Frontispiece.
19 **Freston Tower.** By Rev. R. Cobbold, Author of "Margaret Catchpole," &c. Illustrated.
20 **Holden with the Cords.** By Mrs. W. M. L. Jay.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT HALF-A-CROWN.

Price

THE FAMILY GIFT SERIES.

A cheap issue of Popular Books, suitable for Prizes and Rewards.

Crown 8vo, cloth gilt, price *2s. 6d.* each.

2/6

1 The Swiss Family Robinson. With 200 **Engravings.**
2 Bunyan's Pilgrim's Progress. Memoir. 100 **Illusts.**
3 Robinson Crusoe. Memoir and many **Engravings.**
4 Sandford and Merton. With 100 **Engravings.**
5 Famous Boys, and How they became Great Men.
6 Fifty Celebrated Women. With **Portraits,** &c.
7 The Gentlemen Adventurers. W. H. G. KINGSTON.
8 Evenings at Home. With many **Illustrations.**
9 The Adventures of Captain Hatteras. By JULES VERNE. With Coloured Plates.
10 Twenty Thousand Leagues Under the Sea. By JULES VERNE. With Coloured Plates.
11 The Wonderful Travels. By the same. **Col. Plates.**
12 The Moon Voyage. JULES VERNE. **Coloured Plates.**
13 Getting On in the World. By W. MATHEWS, LL.D.
14 The Boy's Own Book of Manufactures and Industries of the World. With 365 **Engravings.**
15 Great Inventors: The Sources of their Usefulness, and the Results of their Efforts. With 109 **Engravings.**
16 The Marvels of Nature. With 400 **Engravings.**
17 The Boy's Own Sea Stories. With page **Engravings.**
18 Grimm's Fairy Tales. With many **Illustrations.**
19 Fifty Celebrated Men. With **Portraits.**
20 The Wonders of the World. With 123 **Engravings.**
21 Triumphs of Perseverance and Enterprise. **Illust.**
22 Keble's Christian Year. With page **Engravings.**
23 A Face Illumined. By E. P. ROE.
24 The Scottish Chiefs. By Miss JANE PORTER.
25 What Can She Do? By E. P. ROE.
26 Barriers Burned Away. By E. P. ROE.
27 Opening of a Chestnut Burr. By E. P. ROE.
28 Orange Blossoms. By T. S. ARTHUR. **Illustrated.**
29 Mary Bunyan. By S. R. FORD.
30 Margaret Catchpole. By Rev. R. COBBOLD.
31 Julamerk; or, The Converted Jewess. By Mrs. WEBB.
33 Amy and Hester; or, The Long Holidays. **Illustrated.**
34 Edwin and Mary; or, The Mother's Cabinet. **Illustrated.**

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT HALF-A-CROWN.

Price 2/6

THE FAMILY GIFT SERIES—*continued.*

36 **Wonders and Beauties of the Year.** H. G. ADAMS.
37 **Modern Society.** By CATHERINE SINCLAIR.
38 **Beatrice.** By CATHERINE SINCLAIR.
39 **Looking Heavenward:** A Series of Tales and Sketches for the Young. With numerous Illustrations.
40 **Life's Contrasts;** or, The Four Homes. Illustrated.
41 **Nature's Gifts, and How we Use Them.** Illust.
42 **Pilgrims Heavenward:** Counsel and Encouragement.
43 **Children's Hymns and Rhymes.** Illustrated.
44 **Preachers and Preaching,** in Ancient and Modern Times. By Rev. HENRY CHRISTMAS. With Portraits.
45 **Character and Culture.** By the BISHOP OF DURHAM.
46 **Popular Preachers:** Their Lives and their Works.
47 **Boy's Handy Book of Games and Sports.** Illust.
48 **Boy's Handy Book of Natural History.** Illust.
49 **A Knight of the Nineteenth Century.** E. P. ROE.
50 **Near to Nature's Heart.** By E. P. ROE.
51 **A Day of Fate.** By E. P. ROE.
52 **Odd or Even?** By Mrs. WHITNEY.
53 **Gutenburg, and the Art of Printing.** Illustrated.
54 **Uncle Mark's Money;** or, More Ways than One.
55 **Without a Home.** By E. P. ROE.
56 **The Arabian Nights' Entertainments.** Illustrated.
57 **Andersen's Popular Tales.** Illustrated.
58 **Andersen's Popular Stories.** Illustrated.
59 **Lion Hunting.** By GERARD. Illust. by DORE and others.
60 **The Backwoodsman.** Ed. by Sir C. F. L. WRAXALL.
61 **The Young Marooners.** By F. R. GOULDING. Illust.
62 **The Crusades and Crusaders.** By J. G. EDGAR. Do.
63 **Hunting Adventures in Forest and Field.** Illust.
64 **The Boy's Book of Modern Travel and Adventure.**
65 **Famous People and Famous Places.** Illustrated.
66 **Cheerful Homes;** How to Get and Keep them. By the Author of "Buy your Own Cherries," &c. Illustrated.
67 **Helen.** By MARIA EDGEWORTH.
68 **Our Helen.** By SOPHIE MAY.
69 **The Little Ragamuffins of Outcast London.** By the Author of "A Night in a Workhouse," &c. Illustrated.
70 **Heaven's Messengers:** A Series of Stirring Addresses.
71 **From Log Cabin to White House:** The Life of General GARFIELD. Illustrated.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT HALF-A-CROWN.

Price

2/6

THE FAMILY GIFT SERIES—*continued.*

72 **His Sombre Rivals.** By E. P. ROE.
73 **Reedyford**; or, Creed and Character. By S. K. HOCKING.
90 **England's Hero and Christian Soldier**: The Life of General GORDON. **Maps and Illustrations.**
91 **From Jest to Earnest.** By E. P. ROE.
92 **The Manners of Polite Society.**
93 **Beeton's Great Orators and Great Orations.**
94 **The Art of Public Speaking, and Curiosities of** Orators and Oratory.
95 **Wild Sports of the World.** By JAMES GREENWOOD. **Profusely Illustrated.**
96 **Brave British Soldiers and the Victoria Cross.** With numerous **Engravings.**
97 **Silas Horner's Adventures.** By JAMES GREENWOOD. **Profusely Illustrated.**
98 **The Life of Lord Beaconsfield**: Literary and Political.
99 **The New Evenings at Home**; or, Chats about Knowledge. By the Author of "Picciola." **Illustrated.**
100 **An Original Belle.** By E. P. ROE. With Frontispiece.
101 **Only Give Me a Chance.** A Story founded on Fact. By Dr. KIRTON, Author of "Buy Your Own Cherries." **Illust.**
102 **The History of Napoleon Bonaparte.** **Illustrated.**

THE BOYS' ILLUSTRATED LIBRARY OF

HEROES, PATRIOTS, & PIONEERS.

The Story of their Daring Adventures and Heroic Deeds.

In this series Biographies are narrated exhibiting the force of character of the men and the remarkable adventures they encountered, and these records can scarcely be perused without exciting a feeling of admiration for the Heroes and of wonder at the magnitude of their achievements.

In picture boards, ***2s.***; cloth gilt, ***2s. 6d.***; gilt edges, ***3s. 6d.***

2/–
2/6
3/6

1 **Columbus**, the Discoverer of the New World.
2 **Franklin**, Printer Boy, Statesman, and Philosopher.
3 **Washington**, Hero and Patriot.
4 **The Puritan Captain**; or, The Story of Miles Standish.
5 **Boone, the Backwoodsman**, the Pioneer of Kentucky.
6 **The Terror of the Indians**; or, Life in the Backwoods.
7 **The Hero of the Prairies**; or, The Story of Kit Carson.
8 **The Spanish Cavalier**; or, De Soto, the Discoverer.
9 **Through Prairie and Forest**; or, De Salle, the Pathfinder.
10 **The Shawnee Prophet**; or, The Story of Tecumseh.
11 **The Buccaneer Chiefs**; or, Captain Kidd and the Pirates.
12 **Red Eagle**; or, The War in Alabama.
13 **The Rival Warriors**; Chiefs of the Five Nations.
14 **The Indian Princess**; or, The Story of Pocohontas.
15 **The Mexican Prince**; or, The Story of Montézuma.
16 **On Board the "Rocket:"** The Story of a Cruise.

GIFT BOOKS AT EIGHTEENPENCE EACH.

Price

THE LILY SERIES.

Very attractively bound in cloth, with design in gold and silver, price *1s. 6d.*; also in cloth gilt, bevelled boards, gilt edges, *2s.*; or ornamental wrapper, *1s.*

Forming admirable Volumes for School Prizes and Presents to Young Ladies.

The design of this Series is to include no books except such as are peculiarly adapted, by their high tone, pure taste, and thorough principle, to be read by those persons, young and old, who look upon books as upon their friends—only worthy to be received into the Family Circle for their good qualities and excellent characters. So many volumes now issue from the press low in tone and lax in morality that it is especially incumbent on all who would avoid the taint of such hurtful matter to select carefully the books they would themselves read or introduce to their households. In view of this design, no author whose name is not a guarantee of the real worth and purity of his or her work, or whose book has not been subjected to a rigid examination, will be admitted into "THE LILY SERIES."

1/-
1/6
and
2/-

1 **A Summer in Leslie Goldthwaite's Life.** By Mrs. WHITNEY.
Such books as hers should be in every household.

2 **The Gayworthys:** A Story of Threads and Thrums. Ditto.
A work to be read, loaned, re-read, and re-loaned.

3 **Faith Gartney's Girlhood.** By Mrs. WHITNEY.
Mrs. Whitney's writings have a mission, which is to make the world better than they find it.

4 **The Gates Ajar.** By ELIZABETH STUART PHELPS.
A book that has brought happiness to many a sorrowing spirit.

5 **Little Women.** By Miss ALCOTT, Author of "Good Wives."
A book which all girls would be better for reading.

6 **Good Wives.** Sequel to "Little Women." By the same.
No better books could be put into young girls' hands than "Little Women" and "Good Wives."

7 **Alone.** By MARION HARLAND, Author of "The Hidden Path."
Its merits consist in its truthfulness to nature, and the fervent spirit which animates its narration.

8 **I've Been Thinking.** By A. S. ROE.
Few writers excel this excellent author in pure simplicity of style, natural interest, and truthfulness of narrative.

9 **Ida May.** By MARY LANGDON.
The narrative of "Ida May" is one of intensest interest.

10 **The Lamplighter.** By Miss CUMMING.
The story of an orphan girl's struggles and triumphs.

11 **Stepping Heavenward.** By E. PRENTISS.
Should be in every family. Abounds in passages of deep pathos and tenderness.

12 **Gypsy Breynton.** By the Author of "The Gates Ajar."
The "Gypsy" books are charming reading.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT EIGHTEENPENCE EACH.

Price
1/-
1/6
and
2/-

THE LILY SERIES—*continued.*

13 **Aunt Jane's Hero.** Author of "Stepping Heavenward."
The object of "Aunt Jane's Hero" is to depict a Christian Home, whose happiness flows from the living rock, Christ Jesus.

14 **The Wide, Wide World.** By Miss WETHERELL.
Dear to every girl who has read it.

15 **Queechy.** By the Author of "The Wide, Wide World."
A fascinating story, fresh and true to life.

16 **Looking Round.** By the Author of "I've been Thinking."
His books are just the sort to put into the hands of youth.

17 **Fabrics:** A Story of To-Day.
Full of interest, and cannot fail to secure a wide popularity.

18 **Our Village:** Tales. By MISS MITFORD.
An engaging little volume, full of feeling, spirit, and variety.

19 **The Winter Fire.** By ROSE PORTER.
Cannot fail to make its way in domestic circles, especially where religion is held to be of the first moment.

20 **The Flower of the Family.** By Mrs. E. PRENTISS.
The "Flower of the Family" abounds with admirable moral lessons.

21 **Mercy Gliddon's Work.** By the Author of "The Gates Ajar."
Earnest in tone and interesting in style.

22 **Patience Strong's Outings.** By Mrs. WHITNEY.
A more wholesome or readable book it would be difficult to find.

23 **Something to Do.** By the Author of "Little Women," &c.
Miss Alcott's writings are as charming in style as they are pure in tone.

24 **Gertrude's Trial.** By MARY JEFFERIS.
This book has given comfort to many a sorrowing heart and counsel to many an erring soul.

25 **The Hidden Path.** By the Author of "Alone."
An extremely interesting story.

26 **Uncle Tom's Cabin.** By Mrs. H. B. STOWE. Illustrated.
No work of fiction has ever approached the popularity of "Uncle Tom's Cabin."

27 **Fireside and Camp Stories.** By the Author of "Little Women."
These are tales, some of a stirring and some of a domestic character, suited to all tastes.

28 **The Shady Side.** By a Pastor's Wife.
A true and interesting record of a young person's life and troubles.

29 **The Sunny Side.** By H. TRUSTA.
A worthy companion in all respects to the popular volume, "The Shady Side."

30 **What Katy Did.** By SUSAN COOLIDGE.
A pleasant and naturally written tale.

31 **Fern Leaves from Fanny's Portfolio.** By FANNY FERN.
Fanny Fern's inspiration comes from nature.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT EIGHTEENPENCE EACH.

Price

1/-

1/6

and

2/-

THE LILY SERIES—*continued.*

32 **Shadows and Sunbeams.** By FANNY FERN.
She dips her pen in her heart and writes out her own feelings.

33 **What Katy Did at School.** By SUSAN COOLIDGE.
A fascinating work for girls.

34 **Shiloh**; or, Without and Within. By Mrs. W. M. L. JAY.
The plot is interesting, whilst the lessons it inculcates should make it a welcome addition to every family library.

35 **The Percys.** By the Author of "Stepping Heavenward."
A picture of a genial, happy Christian home.

36 **Gypsy's Sowing and Reaping.** By E. STUART PHELPS.
A domestic story, healthy in tone, and told in a lively style.

37 **Gypsy's Cousin Joy.** By the same.
A Sequel to "Gypsy Breynton."

38 **Gypsy's Year at the Golden Crescent.** By the same.
A Sequel to "Gypsy's Cousin Joy."

39 **Miss Edgeworth's Moral Tales.**
Remarkable for their humane sympathies and moral tendencies.

40 **Miss Edgeworth's Popular Tales.**
Miss Edgeworth is the author of works never to be forgotten—which can never lose their standard value as English Classics.

41 **The Prince of the House of David.** By Rev. J. H. INGRAHAM.
Relates with deep reverence the scenes in the life of Jesus.

42 **Anna Lee.** By T. S. ARTHUR.
An amusing and instructive story, conveying some valuable lessons.

43 **The Throne of David.** By the Rev. J. H. INGRAHAM.
The aim of the writer is to invest with popular interest one of the most interesting periods of Hebrew History.

44 **The Pillar of Fire.** By the Rev. J. H. INGRAHAM.
The author's aim has been to unfold the beauties, riches, eloquence, and grandeur of the Holy Scriptures.

45 **Prudence Palfrey.** By T. B. ALDRICH.
The author sketches his characters admirably.

46 **A Peep at Number Five.** By H. TRUSTA.
The sentiments of this book are pure and the language good.

47 **Marjorie's Quest.** By JEANNIE T. GOULD.
A capital tale, full of interest.

48 **Our Village:** Country Pictures. By Miss MITFORD.
The descriptions in this work are very vivid and glowing.

49 **Woman Our Angel.** Sequel to "Looking Round."
Can be read and re-read with profit and increasing delight.

50 **How Marjory Helped.** By M. CARROLL.
A story well told, and written in a religious spirit.

51 **Mabel Vaughan.** By the Author of "The Lamplighter."
A charming story, thoroughly sustaining the author's reputation.

52 **Melbourne House.** Author of "The Wide, Wide World."
Another of Miss Warner's bright and beautiful creations.

53 **Father Clement.** By GRACE KENNEDY.
Her writings are religious, but are most entertaining.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT EIGHTEENPENCE EACH.

Price
1/-
1/6
and
2/-

THE LILY SERIES—*continued.*

54 **Dunallan.** By GRACE KENNEDY.
Her writings possess irresistible charms to multitudes of readers.

55 **From Jest to Earnest.** By Rev. E. P. ROE.
While Mr. Roe tells a story admirably well, and paints with the skill of a master, he carefully eschews sensationalism.

56 **Jessamine.** By MARION HARLAND.
A sweet and interesting story.

57 **Miss Gilbert's Career.** By J. G. HOLLAND.
Remarkable for moral purpose and sympathetic touches.

58 **The Old Helmet.** Author of "The Wide, Wide World."
The story is admirably told, and its lessons are many and valuable.

59 **Forging their Own Chains.** By C. M. CORNWALL.
Admirably written; conveys some valuable lessons.

60 **Daisy.** Sequel to "Melbourne House." By E. WETHERELL.
Leaves nothing to be desired save a re-perusal.

61 **Our Helen.** By SOPHIE MAY.
As free from the sensational ana impossible as could be desired.

62 **That Lass o' Lowrie's.** By F. H. BURNETT.
One of the sweetest tales ever written.

63 **The Years that are Told.** By the Author of "The Winter Fire."
Unexceptionable as to moral principle and refinement of tone.

64 **Near to Nature's Heart.** By Rev. E. P. ROE.
The high and wholesome lesson of each of this author's works is not for a moment left in doubt or obscurity.

65 **Esther Douglas,** and other Stories. By MARY BASKIN.
A story by a new author, worthy of acceptance by all readers.

66 **A Knight of the Nineteenth Century.** By E. P. ROE.
Contains the elements of perfect work, clearness and brilliancy of style, beauty of expression, and a most excellent moral.

67 **Released.** By the Author of "Esther Douglas."
A most interesting story, with a high moral tone.

68 **Quinnebasset Girls.** By ROSE PORTER.
A most delightful story for girlhood.

69 **Helen.** By MARIA EDGEWORTH.
The most popular of Miss Edgeworth's brilliant novels.

70 **The Fairchild Family.** By Mrs. SHERWOOD.
Shows the importance and effects of a religious education.

71 **Freston Tower.** By the Author of "Margaret Catchpole."
An interesting story of the times of Cardinal Wolsey.

72 **Godwyn's Ordeal.** By Mrs. J. KENT SPENDER.
A tender and graceful story, thoroughly pure in tone.

73 **Madeleine:** A Story of French Love.
A singularly pure and interesting story.

74 **Onward to the Heights of Life.**
A story of a struggle and a victory over temptation.

75 **Percy Harrison's Mistake.**
A new story by the Misses Huntingdon.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT EIGHTEENPENCE EACH.

Price
1/-
1/6
and
2/-

THE LILY SERIES—*continued.*

76 **Carl Krinken.** By ELIZABETH WETHERELL.
Another welcome work by this celebrated author.

77 **Without a Home.** By E. P. ROE.
An interesting story of the time of the American Civil War.

78 **Her Wedding Day.** By MARION HARLAND.
Will be heartily welcomed by all who have read "Alone."

79 **His Sombre Rivals.** By E. P. ROE.
The author's rush of incident, clear, vigorous style, and other qualities, are present in full strength.

80 **Odd or Even.** By MRS. WHITNEY.
Healthful and stimulating, as well as extremely interesting.

81 **Julamerk.** By MRS. WEBB.
A remarkable instance of the saving power of Faith.

82 **Martyrs of Carthage.** By MRS. WEBB.
An interesting narrative of the times of the early Christian converts.

83 **The Nun.** By MRS. SHERWOOD.
A valuable narrative, exposing the dangers of false doctrine.

84 **The Basket of Flowers.**
Long one of the most popular of children's stories.

85 **Autobiography of a £5 Note.** By MRS. WEBB.
Sermons may be found in stones, and lessons in a £5 note.

86 **Pilgrims of New England.** By MRS. WEBB.
A sympathetic account of the trials of the early Puritan settlers.

87 **Only a Dandelion.** By MRS. PRENTISS.
A collection of stories from the pen of a charming writer.

88 **Follow Me.** By MRS. PRENTISS.
Another collection by this ever-welcome authoress.

89 **Nidworth.** By MRS. PRENTISS.
This story of the "Three Magic Wands" may be read by all with advantage.

90 **Nellie of Truro.** A Tale from Life.
A stirring and remarkably interesting story of courage and adventure.

91 **An Original Belle.** By E. P. ROE.
This new story by Mr. Roe bids fair to attain greater popularity than any of its predecessors.

That the love of good literature has developed is practically shown by the unparalleled success of the series of pure, healthy, and improving books entitled the LILY SERIES.

ABOUT THREE MILLION VOLUMES

have been printed; and on the very moderate assumption that each copy has been perused by six persons, the LILY SERIES *may claim* EIGHTEEN MILLIONS OF READERS. *The statistics of such an undertaking generally possess a certain interest for the public, and it may be stated, accordingly, that above* TWENTY-FOUR THOUSAND REAMS OF PAPER, *representing a weight of* **FOUR HUNDRED AND TWENTY-THREE TONS,** *or nine hundred and forty-eight thousand three hundred and nineteen pounds, have been worked up in the three million copies of the* LILY SERIES.

WARD, LOCK & CO., London, Melbourne, and New York.

Price

TEXT BOOKS.

5/- **THE CHRISTIAN TEXT BOOK AND BIRTHDAY REMEMBRANCER.** A Book of Sacred Counsel and Reflections for Every Day in the Year. With **Interleaved Pages** for recording Birthdays and registering Thoughts and Events of Every Day. In handsome binding, cloth gilt extra, red burnished edges, price *5s.*

BIRTHDAY TREASURE SERIES.

Demy 32mo, cloth, gilt edges, each *1s.*; full-calf, ivory enamel, morocco, paste grain, polished wood or russia, *2s. 6d.*; full-calf circuit, or morocco circuit, *4s.*

1/- to 4/-

1 **Christian Daily Text Book and Birthday Record.**
2 **The Christian Daily Treasure Book of Sacred** Verse and Holy Counsel, with Birthday Souvenir.
3 **Golden Truths and Birthday Note Book.**
4 **Shakespeare Gem Book and Birthday Journal.**
5 **The Child's Own Text Book and Birthday Register.**
6 **The Loving Record**; or, Poetic Remembrancer of Anniversaries of Wedding Days, Birthdays, &c., for Every Day.
7 **The Christian Year Birthday Book.** Selections for Every Day from Keble's "Christian Year," with Birthday Register.
8 **The Bunyan Text Book and Birthday Remembrancer.** Quotations for Every Day from the Works of John Bunyan.
9 **Kirton's Temperance Daily Text Book and Birthday Record.**
10 **The Longfellow Birthday Book.**

MINIATURE TEXT BOOKS.

Demy 32mo, cloth gilt, price *6d.* each.

6d.

1 **The Miniature Text Book.**
2 **The Miniature Treasure Book.**
3 **The Miniature Book of Golden Truths.**
4 **The Miniature Shakespeare Gem Book.**
5 **The Miniature Child's Own Daily Text Book.**

2/6 **THE LANGUAGE AND POETRY OF FLOWERS.** With **Coloured Plates** and many other **Illustrations.** Fcap. 8vo, cloth gilt, red edges, *2s. 6d.*

1/- **THE LANGUAGE OF FLOWERS.** With **Coloured Frontispiece** and other **Illustrations.** Fcap. 8vo, cloth gilt, *1s.*; Pocket Edition, demy 32mo, cloth, gilt edges, *6d.*

1/- **THE POETRY OF FLOWERS.** With **Coloured Frontispiece** and other **Illustrations.** Fcap. 8vo, cloth gilt, *1s.*; Pocket Edition, demy 32mo, cloth, gilt edges, *6d.*

MISCELLANEOUS WORKS.

Price

KIRTON'S STANDARD RECITERS.

Containing over One Thousand Choice Selections of Prose and Poetical Recitations, Readings, and Dialogues.

Edited by J. W. KIRTON, LL.D., Author of "Buy Your Own Cherries."

Appropriate headings are placed over each subject, indicating the style in which it should be given; each piece is printed and marked so as to guide the most inexperienced to a proper delivery; each volume has a complete index; no piece appears more than once; hints and instructions are given to young beginners.

Fcap. 8vo, neat cloth, price *1s.* each; cloth gilt, *1s. 6d.* each.

1/– 1 Kirton's Standard Temperance Reciter.
2 Kirton's Standard Sunday School Reciter.
3 Kirton's Standard Popular Reciter.
4 Kirton's Standard Comic Reciter.
5 Kirton's Standard Speaker and Elocutionist.
6 Kirton's Standard Band of Hope Reciter.
7 Kirton's Standard Temperance Dialogues.
8 Kirton's Standard Popular Dialogues.

Fcap. 8vo, cloth gilt, price *3s. 6d.* each.

3/6 KIRTON'S ELOCUTIONIST AND PUBLIC SPEAKER. A Guide to the Art of Reading and Elocution.

3/6 KIRTON'S SOCIAL AND RELIGIOUS RECITER. A Collection of Dialogues, Recitations, and Readings.

3/6 MOXON'S STANDARD READINGS AND RECITATIONS. Edited by THOMAS HOOD. Fcap. 8vo, cloth gilt, price *3s. 6d.*
1/– Also to be had in Three Vols., cloth, price *1s.* each.

6/– WILLIAM EWART GLADSTONE: A Critical and Literary Biography. By G. R. EMERSON, Editor of "Beeton's Illustrated Encyclopædia." Library Edition, demy 8vo, cloth gilt, price *6s.*

7/6 TRAVELS AND ADVENTURES IN ARABISTAN; or, The Land of the Arabian Nights. By W. P. FOGG, A.M. Introduction by BAYARD TAYLOR. **Illustrated.** Demy 8vo, cloth gilt, *7s. 6d.*

6/– TRAVELS IN PORTUGAL. By JOHN LATOUCHE. **Map and Photograph.** Third and Revised Edition. Crown 8vo, *6s.*

BEETON'S BOY'S PRIZE LIBRARY.

Demy 8vo, cloth gilt, *5s.* each; gilt edges, *6s.* each.

5/– 5 Beeton's Hero Soldiers, Sailors and Explorers. 890 pp., with **36 page Plates** and **156 Woodcuts.**

7 Beeton's Victorious English Sea Stories, Tales of Enterprise and School Life. 1,050 pp., with **Coloured Frontispiece, 46 full-page Plates, and 150 Woodcuts.**

Price

BOYS' ILLUSTRATED VOLUMES.

No better Library could be chosen for the selection of Prizes for Young Gentlemen, Birthday Gifts, or Anniversary Rewards.

Crown 8vo, handsomely bound, cloth gilt, gilt edges, *5s.*

5/-

2 **The Boy's Handy Book of Games, Sports, Pastimes,** and Amusements. With **Hundreds of Engravings.**

3 **The Boy's Handy Book of Natural History.** With nearly **100 page Engravings** by William Harvey.

6 **Ice World Adventures**; or, Voyages and Travels in the Arctic Regions. By James Mason. With **37 Plates, Map,** and many **Engravings** in the Text.

7 **The Boy's Own Book of Manufactures and Industries** of the World. With **365 Engravings** by Dalziel Brothers.

8 **Evenings at Home**; or, The Juvenile Budget Opened. By Dr. Aiken and Mrs. Barbauld. With many **Engravings.**

9 **The History of Sandford and Merton.** By Thomas Day. With **100 Engravings** by Dalziel Brothers.

10 **The Swiss Family Robinson.** Specially Translated and Compiled from the best Original Editions, by Henry Frith. With **200 Engravings.**

11 **The Arabian Nights' Entertainments.** With full-page **Engravings** by Millais, Tenniel, &c.

12 **The Boy's Book of Modern Travel and Adventure.** With numerous **Illustrations.**

13 **The Young Marooners**; or, The Adventures of Robert and Harold on the Florida Coast. By F. R. Goulding. With numerous **Illustrations.**

14 **The Crusades and Crusaders**: The Story of the Struggle for the Holy Sepulchre. By J. G. Edgar, Author of "How I Won my Spurs." **Illustrated.**

15 **Great Inventors**: The Sources of their Usefulness and the Results of their Efforts. With **109 Engravings** by Dalziels.

16 **Hunting Adventures in Forest and Field.** By "The Old Shekarry." With full-page **Engravings.**

17 **Boy's Own Book of Home Pets**: How to Rear and Manage Them. With **Coloured Plates and 200 Engravings** by Harrison Weir.

18 **The Scottish Chiefs.** By Jane Porter. **Illustrated.**

19 **The Boy's Own Sea Stories.** **Illustrated.**

20 **From Log Cabin to White House**: The Story of President Garfield's Life. By W. M. Thayer. **Illustrated.**

21 **The Little Ragamuffins of Outcast London**: A Story of the Sufferings and Sorrows of the Poor. By the Author of "A Night in a Workhouse," &c. **Illustrated.**

22 **England's Hero and Christian Soldier**: The Life of General Gordon. With **Portrait, Map of the Nile, Bird's-Eye View of Khartoum, and numerous Engravings.**

23 **The History of Napoleon Buonaparte.** **Illustrated.**

GIFT BOOKS AT FIVE SHILLINGS.

Price

BEETON'S BOY'S OWN LIBRARY.

*** *The best set of Volumes for Prizes, Rewards, or Gifts to English Lads. They have all been prepared with a view to their fitness in manly tone and handsome appearance for Presents for Youth.*

Demy 8vo, cloth gilt, price *5s.* each; gilt edges, *6s.* each.

5/-

1 **Stories of the Wars, 1574–1658.** By JOHN TILLOTSON. With Coloured Pictures and many other Illustrations.

2 **A Boy's Adventures in the Barons' Wars.** By J. G. EDGAR. Coloured Frontispiece and many Illustrations.

3 **Cressy and Poictiers**; or, The Story of the Black Prince's Page. By J. G. EDGAR. With Coloured Frontispiece and many Illustrations, principally by R. DUDLEY and GUSTAVE DORE.

4 **Runnymede and Lincoln Fair**: A Story of the Great Charter. By J. G. EDGAR. With Coloured Frontispiece and many Engravings.

5 **Wild Sports of the World.** By JAMES GREENWOOD. Coloured Plates and many Illustrations.

6 **The Wild Man at Home**; or, Life in Savage Lands. By J. GREENWOOD. Coloured and other Illustrations.

7 **Hubert Ellis**: A Story of Richard the Second's Days. By F. DAVENANT. Coloured and other Illustrations.

8 **Don Quixote.** With nearly 700 Illustrations.

9 **Gulliver's Travels.** With Coloured Frontispiece and 300 Woodcuts.

10 **Robinson Crusoe.** Memoir. With Coloured and other Illustrations.

11 **Silas, the Conjuror**: His Travels and Perils. By JAMES GREENWOOD. With many Illustrations.

12 **Scenes and Sports in Savage Lands.** By JAMES GREENWOOD. With Coloured and other Illustrations.

13 **Reuben Davidger**: His Perils and Adventures. By JAMES GREENWOOD. With numerous Illustrations.

14 **Brave British Soldiers and the Victoria Cross.** Stories of the Deeds which won the Prize "For Valour." Illust.

15 **Zoological Recreations.** By W. J. BRODERIP, F.R.S. With Coloured Frontispiece and many Engravings.

16 **Wild Animals in Freedom and Captivity.** With Coloured Frontispiece and 120 Illustrations.

18 **The World's Explorers.** By H. W. DULCKEN, Ph.D. With Coloured Frontispiece and many Illustrations.

19 **The Man among the Monkeys**; or, Ninety Days in Apeland. Illustrated by GUSTAVE DORE.

20 **Great Discoveries and Daring Deeds.** By JOHN TILLOTSON. Illustrated.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT EIGHTEENPENCE EACH.

Price

THE FRIENDLY COUNSEL SERIES.

From first to last the effort has been, and will be, to make the FRIENDLY COUNSEL SERIES *a practical illustration of the homely truth that "A Friend in Need is a Friend Indeed." The object has been kept in view to spread abroad for the reading public the good words of the present, and preserve for them the wisdom of the past.*

Crown 8vo, cloth gilt, price ***1s. 6d.*** each; fancy wrapper, ***1s.***; cloth gilt, gilt edges, price ***2s.***

(Those marked thus (*) can also be had in cloth, extra gilt side, back, and edges, price ***2s. 6d.*** each.)

1/– 1/6 and 2/–

1 ***Timothy Titcomb's Letters addressed to Young People.**
2 ***Beecher's Lectures to Young Men.** By HENRY WARD BEECHER, Author of "Life Thoughts."
3 ***Getting On in the World**; or, Hints on Success in Life. By WILLIAM MATHEWS, LL.D. First Series.
4 ***Cobbett's Advice to Young Men.** Notes and Memoir.
5 **Christians in Council**; or, The Pastor and his Friends. By the Author of "Stepping Heavenward."
6 **How to Make a Living.** By GEORGE CARY EGGLESTON.
7 **Hufeland's Art of Prolonging Life.** By Dr. HUFELAND. Revised.
8 ***Foster's Decision of Character,** and other Essays. With Life of the Author and Notes.
9 ***Getting On in the World.** MATHEWS. Second Series.
10 ***How to Excel in Business**; or, The Clerk's Instructor. By JAMES MASON.
11 ***Todd's Student's Manual.** Notes by the Author.
12 **How to Excel in Study**; or, The Student's Instructor. By JAMES MASON, Author of "How to Excel in Business," &c.
13 **Money**: How to Get, How to Use, and How to Keep it.
14 **Oratory and Orators.** By W. MATHEWS, LL.D., Edited by J. W. KIRTON, LL.D.
17 **Todd's Sunday School Teacher.** By Rev. JOHN TODD, D.D.
18 **Todd's Lectures for Children.** By Rev. JOHN TODD.
19 **Todd's Simple Sketches and Truth Made Simple.**
20 **Stepping Stones to Thrift**: A Guide to Success in Life.

Crown 8vo, bevelled boards, cloth gilt, gilt edges, ***5s.***

5/– **The Friendly Counsellor.** Containing "Timothy Titcomb's Letters to Young People." "Cobbett's Advice to Young Men," and "Beecher's Lectures to Young Men."

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT EIGHTEENPENCE EACH.

Price

1/-
1/6
and
2/-

YOUTH'S LIBRARY OF WONDER & ADVENTURE.

Crown 8vo, cloth gilt, *1s. 6d.;* picture wrapper, *1s.;* gilt edges, *2s.*

1 A Journey into the Interior of the Earth. VERNE.
2 The English at the North Pole. By JULES VERNE.
3 The Ice Desert. By JULES VERNE.
4 Five Weeks in a Balloon. By JULES VERNE.
5 The Mysterious Document. By JULES VERNE.
6 On the Track. By JULES VERNE.
7 Among the Cannibals. By JULES VERNE.
8 Twenty Thousand Leagues Under the Sea. Part I.
9 ———————————— Part II.
10 Two Years Before the Mast. By R. H. DANA.
11 From the Earth to the Moon. By JULES VERNE.
12 Round the Moon. By JULES VERNE.
13 Sandford and Merton. Illustrated.
14 Baron Munchausen: His Travels and Adventures. Illust.
15 Robinson Crusoe. With many Engravings.
16 Around the World in Eighty Days. By JULES VERNE.
17 A Boy's Life Aboard Ship, as it is. Illustrated.
18 Life in a Whaler: Adventures in Tropical Seas. Illust.
19 Grimm's Fairy Tales. Illustrated.
20 The Marvels of Nature. With 400 Engravings.
21 Wonders of the World. With 123 Engravings.
22 The Boy's Own Book of Manufactures and Industries of the World. With 365 Engravings.
23 Fifty Famous Men. With Portraits and other Illusts.
24 Great Inventors. With 109 Engravings.
25 The Boy's Handy Book of Games. Illustrated.
26 The Boy's Handy Book of Natural History. Illust.
27 Bunyan's Pilgrim's Progress. 100 Engravings.
28 Evenings at Home. With many Engravings.
29 Famous Boys. With Portraits, &c.
30 Arabian Nights' Entertainments. Illustrated.
31 Andersen's Popular Tales. Illustrated.
32 Andersen's Popular Stories. Illustrated.
33 The Young Marooners. By F. GOULDING. Illustrated.
34 The Crusades and Crusaders. By J. G. EDGAR. Illust.
36 Lion Hunting. By JULES GERARD. Illustrated.
37 The Backwoodsman. By Sir C. F. L. WRAXALL.
38 Hunting Adventures in Forest and Field.
39 The Boy's Book of Modern Travel and Adventure.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS AT EIGHTEENPENCE.

Price 1/- 1/6 and 2/-

THE YOUTH'S LIBRARY—*continued.*

40 **From Log Cabin to White House.** Illustrated.
42 **England's Hero and Christian Soldier:** The Life of General GORDON. Maps and Engravings.
43 **Wild Sports of the World.** GREENWOOD. Illustrated.
44 **Brave British Soldiers and the Victoria Cross.** Do.
45 **Silas Horner's Adventures.** GREENWOOD. Illustrated.
46 **Robinson Crusoe.** Demy 8vo. Profusely Illustrated.
47 **The Noble Wife**; or, Faithful unto Death. Illustrated.
48 **The Triumph of Truth**; or, Honesty the Best Policy.
49 **The Faithful Servant**; or, The King and the Peasant.
50 **The Widow's Son**; or, Bread upon the Waters. Illust.
51 **The Greek Slave**; or, Filial Love. Illustrated.
52 **The Hero Martyr**; or, The Faithful Protestant. Illust.
53 **The Pilgrim Kings**; or, The Star of Bethlehem. Illust.
54 **The Child's Life of Jesus Christ.** Illustrated.
55 **The Good Sailor Boy**; or, Adventures of Charley Morant.
56 **The Christian Prince**: A Historical Narrative. Illust.
57 **The Faithful Missionary**; or, Life in Greenland. Illust.
58 **The Boy Pilot**: An Iceland Narrative. Illustrated.
59 **Fidelity Rewarded.** By FRANZ HOFFMANN. Illust.
60 **Virtue Triumphant**; or, Anton, the Fisherman. Illust.
61 **Famous Friendships** of Eminent Men and Women. Do.
62 **Romantic Tales of Royal Palaces.** Illustrated.
63 **Notable Women of Our Own Time.** Portraits.
64 **William Ewart Gladstone**: A Biography. Portrait.

ERCKMANN-CHATRIAN LIBRARY.

1/- to 3/6

Post 8vo, picture wrapper, price *1s.* each; cloth gilt, *1s. 6d.*; cloth gilt, (those marked * with page Engravings), *2s. 6d.* each.

The addition to these volumes of the charming Illustrations of SCHULER, BAYARD, *and others render them in every way perfect.*

*1 **Madame Therese.**
2 **The Conscript.**
*3 **The Great Invasion.**
4 **The Blockade.**
*5 **The States-General.**
*6 **The Country in Danger.**
7 **Waterloo.**
*8 **Dr. Matheus.**
*9 **Stories of the Rhine.**
*10 **Friend Fritz.**
*11 **The Alsatian Schoolmaster.**
*12 **The Polish Jew.**
13 **Master Daniel Rock.**
*15 **Year One of the Republic.**
*16 **Citizen Bonaparte.**
*17 **Confessions of a Clarionet Player.**
*18 **Campaign in Kabylia.**
*19 **The Man Wolf.**
*20 **The Wild Huntsman.**

2/-

DOUBLE VOLUMES. Crown 8vo, picture boards, *2s.* each.

1 **Under Fire.** [1789-1793.
3 **The Story of a Peasant,**
5 **The Mysterious Doctor.**
6 **The Buried Treasure.**
7 **The Old Schoolmaster.**
8 **Weird Tales of the Woods.**

5/-

In new and handsome binding, cloth gilt, gilt top, *5s.* each.

The Story of a Peasant, 1789-1792. **57 Page Illusts.**
The Story of a Peasant, 1793-1815. **60 Page Illusts.**

WARD, LOCK & CO., London, Melbourne, and New York.

PICTURE BOOKS FOR CHILDREN.

Price	
	Messrs. WARD, LOCK AND CO. *have much pleasure in calling the attention of the Public to their various Amusing and Instructive Books for Nursery and Play-room use. These comprise many old favourites, together with newer and equally attractive works. It has been the endeavour of the publishers to combine the instructive with the amusing element, wherever this could be effected without taking away, or even lessening, the charm of the books as vehicles for recreation.*
7/6	**THE OLD FAVOURITE FAIRY TALES:** Told for the Hundredth Time. By H. W. DULCKEN, Ph.D. With **Coloured Pictures and 300 other Illustrations.** Demy 8vo, cloth gilt, bevelled boards, gilt edges, *7s. 6d.*
7/6	**THE OLD FAVOURITE NURSERY RHYMES,** Stories and Ballads. With **Coloured Front. and Hundreds of Engravings.** Demy 8vo, cloth gilt, bevelled boards, gilt edges, *7s. 6d.*
7/6	**DON QUIXOTE DE LA MANCHA.** By CERVANTES. With **Coloured Pictures** and nearly 700 **Engravings** by TONY JOHANNOT. Demy 8vo, cloth gilt, gilt edges, *7s. 6d.*
7/6	**ROBINSON CRUSOE.** (LIFE AND ADVENTURES OF). With Memoir by H. W. DULCKEN, Ph.D. **Coloured Pictures, full-page Plates,** and many **Woodcuts.** Demy 8vo, cloth gilt, gilt edges, *7s. 6d.*
7/6	**WILD SPORTS OF THE WORLD.** By JAMES GREENWOOD, Author of "Scenes and Sports in Savage Lands," &c. With **Coloured and other Illustrations.** Demy 8vo, cloth gilt, bevelled boards, gilt edges, *7s. 6d.*
5/-	**THE CHILD'S POPULAR FAIRY TALES.** Edited by H. W. DULCKEN, Ph.D. With **Coloured Pictures and 276 other Illustrations.** Imp. 16mo, cloth gilt, price *5s.*
3/6	**SACRED STORIES FOR SUNDAY HOURS;** or, Scripture Narratives from the Old Testament. With **Coloured Pictures and 85 Engravings in the Text.** Imperial 16mo, cloth gilt, price *3s. 6d.*
2/6	**THE GOOD SHEPHERD;** or, The Story of Jesus and His Apostles, for the Young. With **Coloured Pictures and other Illustrations.** Imperial 16mo, cloth gilt, *2s. 6d.*
3/6	**ANDERSEN'S POPULAR TALES FOR CHILDREN.** With many **full page and other Illustrations.** Crown 8vo, cloth gilt, *3s. 6d.;* with **Coloured Plates and other Illustrations,** cloth gilt, gilt edges, *5s.*
3/6	**ANDERSEN'S STORIES FOR THE YOUNG.** With many **full-page and other Illustrations.** Crown 8vo, cloth gilt, *3s. 6d.;* with **Coloured Plates and other Illustrations,** cloth gilt, gilt edges, *5s.*
6/-	**DOMESTIC ANIMALS AND THEIR HABITS.** With **Coloured Illustrations,** and Descriptive Matter by H. W. DULCKEN, Ph.D., intended to serve as an Introduction to Natural History. Fcap. folio, cloth gilt, *7s. 6d.;* wrapper boards, *6s.*

PRESENT BOOKS FOR CHILDREN.

Price	
6/–	THE ROYAL INDESTRUCTIBLE PICTURE BOOK. With **Coloured and other Illustrations. Mounted on linen**, folio, cloth gilt, price *7s. 6d.*; picture boards, *6s.*
6/–	THE ROYAL INDESTRUCTIBLE STORY BOOK. With **Coloured Pictures and other Illustrations. Mounted on linen**, folio, cloth gilt, price *7s. 6d.*; picture boards, *6s.*
5/–	MERCIE SUNSHINE'S PICTURE BOOK OF ANIMALS. **Profusely Illustrated.** Royal 4to, cloth gilt, price *6s.*; wrapper boards, *5s.*
5/–	THE CHILDREN'S PICTURE GALLERY. **Profusely Illustrated.** Royal 4to, cloth gilt, price *6s.*; boards, *5s.*
5/–	THE HOLIDAY PICTURE BOOK. **Profusely Illustrated.** Folio, cloth, price *6s.*; boards, *5s.*
5/–	THE NURSERY TREASURE PICTURE BOOK. Full of beautiful **Illustrations.** 4to, cloth gilt, gilt edges, price, *6s.*; boards, price *5s.*
5/–	THE ANIMAL PICTURE BOOK, for Kind Little People. With **large Coloured Pictures and other Illustrations.** 4to, cloth gilt, gilt edges, *6s.*; boards, *5s.*
3/6	AUNT FANNY'S PRETTY PICTURE BOOK. With full-page **Illustrations** printed in **Colours.** Cloth gilt, *3s. 6d.*; or mounted on linen, *5s.*
3/6	AUNT FANNY'S NURSERY TALES AND RHYMES. With **Illustrations in Colours.** Cloth gilt, *3s. 6d.*; or mounted on linen, *5s.*
3/6	THE CHILD'S OWN BOOK OF LARGE COLOURED PICTURES. Folio, cloth gilt, price *3s. 6d.*; picture boards, *2s. 6d.*; **Indestructible Edition**, mounted on linen, boards, *5s.*; cloth, *6s.*
3/6	THE NEW NURSERY PICTURE BOOK. Folio, cloth gilt, price *3s. 6d.*; picture boards, *2s. 6d.*; **Indestructible Edition**, mounted on linen, boards, *5s.*; cloth, *6s.*
3/6	THE NEW PRETTY PICTURE BOOK. Folio, cloth gilt, price *3s. 6d.*; picture boards, *2s. 6d.*; **Indestructible Edition**, mounted on linen, *5s.*; cloth, *6s.*
3/6	THE BOOK OF CHILDREN'S HYMNS AND RHYMES. With **Coloured Frontispiece and numerous Engravings.** Crown 8vo, cloth gilt, gilt edges, *3s. 6d.*; cloth gilt, *2s. 6d.*
3/6	THE STORY OF STORIES; or, Bible Narratives for the Young. By Mrs. LEATHLEY. With full-page **Illustrations.** Crown 8vo, cloth gilt, price *3s. 6d.*
3/6	EDWIN AND MARY; or, The Mother's Cabinet. With **Illustrations.** Crown 8vo, cloth gilt, gilt edges, *3s. 6d.*; cloth gilt, *2s. 6d.*
2/–	THE CHILD'S GUIDE TO KNOWLEDGE. Revised by H. R. HAMILTON. Cloth gilt, price *2s.*

WARD, LOCK & CO., London, Melbourne, and New York.

PRESENT BOOKS FOR CHILDREN.

Price

5/– **AUNT FANNY'S PICTURE PRESENT BOOK.** With many **Illustrations** printed **in Colours**. Cloth gilt, *5s.*

3/– **CHILD'S OWN BOOK OF SCRIPTURE PICTURES,** Old Testament. With over **100 Illustrations**. Folio, wrapper boards, *3s.;* cloth gilt, *5s.*

3/– **CHILD'S OWN BOOK OF SCRIPTURE PICTURES,** New Testament. With over **100 Illustrations**. Folio, wrapper boards, *3s.;* cloth gilt, *5s.*

3/– **THE CHILD'S FAMOUS PICTURE BOOK.** With over **400 Pictures**. Cloth gilt, *5s.;* picture boards, *3s.*

3/– **THE CHILD'S WONDER PICTURE BOOK.** With **Hundreds of Illustrations**. Cloth gilt, *5s.;* picture boards, *3s.*

3/– **THE PRETTY PAGE SCRAP BOOK.** With **Hundreds of Illustrations**. Folio, wrapper boards, *3s.;* cloth gilt, *5s.*

3/6 **THE ROYAL COLOURED PICTURE BOOK.** With **Coloured Pictures** and other **Illustrations**. Folio, picture boards, *3s. 6d.;* cloth gilt, *5s.*

3/6 **THE ROYAL PICTORIAL STORY BOOK.** With **Coloured Pictures** and other **Illustrations**. Folio, picture boards, *3s. 6d.;* cloth gilt, *5s.*

6/– **THE ROYAL NURSERY PICTURE BOOK.** Containing **48 pages of Coloured Pictures**, and 64 pages of descriptive Letterpress and **Engravings**. Folio, picture boards, *6s.;* cloth gilt, *7s. 6d.*

1/– to 2/6 **THE PRINCESS PICTURE BOOK.** With **Coloured and other Illustrations**. Demy 8vo, boards, *1s.*; cloth gilt, *1s. 6d.*; **Indestructible Edition**, boards, *2s.;* cloth gilt, *2s. 6d.*

3/6 **ANN and JANE TAYLOR'S POETRY for CHILDREN.** With full-page and other **Engravings**. Crown 8vo, handsomely bound, cloth gilt, price *3s. 6d.*

5/– **BIBLE STEPS FOR LITTLE PILGRIMS;** or, Scripture Stories for Little Folks. With **Coloured Pictures** and **135** full-page and other **Engravings**. Imperial 16mo, cloth gilt, price *5s.*

Also to be had in 6d. Divisions:

6*d.* 1. The Story of the Creation and the Deluge.—2. The Story of Abraham, Isaac, and Jacob.—3. The Story of Joseph and his Brothers.—4. The Story of Moses.—5. The Story of the Judges.—6. The Story of David.—7. The Story of the Prophets.—8. The Life of Jesus.—9. Stories of the Parables.—10. Stories of the Miracles.—11. Stories of the Apostles.

SIXPENNY COLOURED INDESTRUCTIBLE BOOKS.

Beautifully **printed in Colours**, demy 8vo, on linen, price *6d.* each.

6*d.*
1 The Easy A B C Book.
2 Letter A B C Book.
3 Easy Words and Pretty Pictures.
4 Easy Nursery Rhymes, Old and New.

WARD, LOCK & CO., London, Melbourne, and New York.

PRETTY GIFT BOOKS FOR THE YOUNG.

Price

THE MERCIE SUNSHINE SERIES.

Ornamental boards, price *1s.* per volume; or cloth gilt, price *2s.*

1/-

1 Mercie Sunshine's Chats about Animals. **Illustrated.**
2 Mercie Sunshine's Chats about Birds. **Illustrated.**
3 The Sunny Home. By MERCIE SUNSHINE. **Illustrated.**
4 The Shilling Nursery Rhymes for Children. **Illust.**
5 The Shilling Nursery Rhymes and Stories. **Illust.**
6 The Shilling Funny Nursery Rhymes. **Illustrated.**
7 Old Nursery Tales. With **Coloured Illustrations.**
8 The Cinderella Nursery Story Book. With **Illusts.**
9 Nursery Stories and Pictures for the Young. **Illust.**
10 Nursery Songs With **Coloured and other Illustrations.**
11 Nursery Ballads. With **Coloured and other Illustrations.**
12 Nursery Stories. With **Coloured and other Illustrations.**
13 Sunny Hours. By MERCIE SUNSHINE. **Illustrated.**
14 Wonderful Days; or, Stories for the Little Ones. **Illust.**
15 Wonderful Deeds. With **Coloured and other Illustrations.**
16 Wonderful Lives. With **Coloured and other Illustrations.**
17 The Wonderful Story. With **Coloured and other Illusts.**
18 Wonderful Sayings. With **Coloured and other Illusts.**
19 Irene and the Gipsies. By MERCIE SUNSHINE. **Illust.**
20 The Sparrow's Christmas Party. **Illustrated.**
21 Stories about Pets. By MERCIE SUNSHINE. **Illust.**
22 A Box of Sugar Plums. By MERCIE SUNSHINE. **Illust.**
23 Dickory Dock. By MERCIE SUNSHINE. **Illustrated.**
24 The True Story of the Five Little Pigs. **Illustrated.**
25 Birdie and Bobbie: How they Kept House. **Illustrated.**

THE SUNDAY-SCHOOL LIBRARY.

Illustrated, and attractively bound for Sunday School Rewards, &c.
Fcap. 8vo, cloth gilt, gilt edges, *2s.* each.

2/-

1 The Noble Wife.
2 The Triumph of Truth.
3 The Faithful Servant.
4 The Widow's Son.
5 The Greek Slave.
6 The Hero Martyr.
7 The Pilgrim Kings.
8 Child's Life of Christ.
9 The Good Sailor Boy.
10 The Christian Prince.
11 Faithful Missionary.
12 The Boy Pilot.
13 Fidelity Rewarded.
14 Virtue Triumphant.

INDESTRUCTIBLE TOY BOOKS.

Fcap. 8vo, picture boards, each *1s.*; cloth gilt, *1s. 6d.*

1/-

1 Easy Alphabet Book.
2 Nursery Tales.
3 Nursery Stories.
4 Nursery Pictures.

WARD, LOCK & CO., London, Melbourne, and New York.

GOOD BOOKS FOR LITTLE PEOPLE.

Price

WARD, LOCK & CO.'S

"GOOD AIM" SERIES.

The feature of this series of Books is to encourage in childhood a spirit of love, gentleness, and cheerfulness, while affording amusement and interest.

Elegantly bound, cloth gilt, price *1s.* each.

1/-

1 **The Original Poems for Children.** By ANN and JANE TAYLOR.
2 **The Basket of Flowers.** **Coloured Frontispiece.**
3 **Ellen's Idol.** By E. S. PHELPS. **With Frontispiece.**
6 **Goldy and Goldy's Friends.** **Illustrated.**
7 **The One Thing Needful.** **Illustrated.**
12 **The Orphan Boy**; or, Peasant to Prince. **Illustrated.**
13 **Tom, Tom, the Printer's Son.** **Illustrated.**
14 **Only a Dandelion.** Author of "Stepping Heavenward."
15 **Follow Me.** By the Same. **Illustrated.**
16 **New Year's Bargain.** By SUSAN COOLIDGE. **Illustrated.**
17 **In the Beginning**; or, From Eden to Canaan. **Illust.**
18 **Conquerors and Captives**; or, David to Daniel. **Illust.**
19 **The Star of Promise**; or, Bethlehem to Calvary. **Illust.**
20 **The History of the Robins.** **Illustrated.**
21 **Hymns for Infant Minds.** ANN and JANE TAYLOR.
22 **Rhymes for the Nursery.** ANN and JANE TAYLOR.
23 **Little Susy's Six Birthdays.** By the Author of "Stepping Heavenward." **Illustrated.**
24 **Little Susy's Little Servants.** **Illustrated.**
25 **Little Susy's Six Teachers.** Ditto.
26 **On'y a Penny**; or, One of the Least of These. By the Author of "A Trap to Catch a Sunbeam." **With Illustrations.**
27 **The Contented Home.** Author of "Basket of Flowers."
28 **Help One Another**; or, How to be Happy. **Illustrated.**
29 **Buried in the Snow**: A Tale of the Mountains. **Illust.**
30 **The Lost Child**; or, A Mother's Love. **Illustrated.**
31 **Summer-House Stories.** By Miss M. A. PAULL. **Illust.**
32 **The Child's Own Book of Poetry.** **Profusely Illust.**
33 **Trust in God**; or, The Little Savoyard. **Illustrated.**
34 **Help in Need**; or, Rich and Poor. **Illustrated.**
35 **Dottie and Tottie**; or, Home for the Holidays. **Illust.**
36 **Harry, the Drummer**; or, The Boy Soldier. **Illustrated.**
37 **The Boy's Book of Poetry.** **Illustrated.**
38 **The Girl's Book of Poetry.** **Illustrated.**
39 **Little Henry and his Bearer.** **With Frontispiece.**
40 **The Babes in the Basket.** **With Frontispiece.**
41 **Faithful Georgie.** By GRACE STEBBING. **Illustrated.**
42 **Keble's Christian Year.** **Illustrated.**
43 **Chats about Knowledge**; or, New Evenings at Home.
44 **The Fairy Tales of Science.** By the same Author.

WARD, LOCK & CO., London, Melbourne, and New York.

PRETTY GIFT BOOKS.

Price

THE "LITTLE PET" SERIES.

Imp. 16mo, picture boards, *2s.* each; cloth silvered, *2s. 6d.*

2/6

1 **Our Little Pet's Own Picture Book.** 160 Illustrations.
2 **New Comical Nursery Rhymes & Stories.** Illustrated.
3 **Pretty Little Lessons for Pretty Little Children.** Illust.
4 **Easy Tales and Pleasant Stories.** 200 Engravings.
5 **Bible Sketches from Old and New Testaments.** Illust.
6 **Sacred Readings for Young Children.** 60 Engravings.
8 **The Child's Own Book of Pictures, Tales, and Poetry.**
9 **Favourite Nursery Rhymes for Nursery Favourites.**
10 **Merry Rhymes and Stories.** Illustrated.
11 **Brave Old Ballads.** With Coloured Plates.
12 **Robin Hood, and other Ballads.** With Coloured Plates.
13 **Moral Nursery Tales for Children.** With Illustrations.
14 **Children's Nursery Tales.** With many Illustrations.

HANS ANDERSEN'S STORY BOOKS.

Fcap. 8vo, cloth gilt, with Coloured and other Illustrations, *1s.* each.

1/-

1 **The Christmas Tree.**
2 **The Garden of Paradise.**
3 **The Willow Tree.**
4 **The Silent Book.**
5 **The Little Mermaid.**
6 **The Silver Shilling.**
7 **The Snow Queen.**
8 **The Ice Maiden.**
9 **Little Ida's Flowers.**
10 **Little Tuk.**
11 **What the Moon Saw.**

LARGE-PAGE PICTURE BOOKS.

Folio, ornamental wrappers, *1s.* each.

1/-

1 **The Pleasant Picture** Book.
2 **The Amusing Picture** Book.
4 **The Merry Heart Picture** Book.
6 **The Pretty Rhyme Picture** Book.

THE GOOD GIFT LIBRARY.

Elegantly bound, cloth gilt, price *6d.* each; ornamental wrapper, *3d.*

1 **Little Susy's Little Servants.** By E. PRENTISS.
2 ——— 2nd Series.
3 **Little Susy's Birthdays.**
4 ——— 2nd Series.
5 **Little Susy's Teachers.**
6 **Little Susy's Teachers.** 2nd S.
7 **Original Poems.** By ANN and JANE TAYLOR.
8 ——— 2nd Series.
9 ——— 3rd Series.
10 **Watts's Songs.**

☞ The above can also be had in SHILLING PACKETS; Packet I. containing Nos. 1, 2, 3, and 4, and Packet II. containing Nos. 5, 6, 7, and 8.

WARD, LOCK & CO., London, Melbourne, and New York.

GIFT BOOKS FOR THE YOUNG.

Price

THE DAISY MAYFIELD SERIES.

In picture boards, *3s.* each; or cloth gilt, *5s.*

3/- 2 Merry Sunbeams. With 200 Engravings.
6 The Pretty Gift Book for Good Girls and Boys.
7 The Fireside Picture Book.
8 The Children's Treasure Picture Book.
9 The Nursery Treasure Picture Book.
10 Little Lily's Large-Type Picture Book.
11 The Child's Own Book of Nursery Rhymes, Songs, Pictures and Music.

THE CHILDREN'S SERIES OF

ILLUSTRATED GIFT BOOKS.

Handsomely bound in cloth gilt, picture on cover, *3s. 6d.* each.

3/6 1 Moral Nursery Tales for Children. With many **Engravings.**
2 The Children's Picture Gift Book of Music and Song. With many **Engravings.** (Also in picture boards, *2s. 6d.*)
3 Chats about Animals and Birds. By Mercie Sunshine, Author of "The Sunny Holidays," &c. Beautifully **Illustrated.**
4 The Sunny Holidays; or, The Adventures of the Allen Family. By Mercie Sunshine. Beautifully **Illustrated.**
7 Nursery Songs and Ballads. **Coloured Illustrations.**
8 Nursery Tales and Stories. **Coloured Illustrations.**

THE

SUNBEAM PICTURE BOOK SERIES.

Imperial 16mo, picture boards, *2s.*; cloth gilt, *3s.*

2/- 1 The Primrose Picture Book. With nearly **200 Pictures.**
2 My Little Friend. With nearly **200 Engravings.**
3 The Daisy Picture Book. With about **200 Illustrations.**
4 The Keepsake Picture Book. With **200 Illustrations.**
5 The Golden Story Book. With **200 Illustrations.**
6 Charlie and Rosie. With about **100 Illustrations.**
7 Lottie Lightheart. With about **100 Pictures.**
8 The Happy Home Picture Book. With **100 Illustrations.**
9 Sunny Child Life. With about **100 Illustrations.**

NEW LARGE TYPE PICTURE BOOKS.

1/- 1 Our Baby's Picture Book. Profusely **Illustrated.**
2 Child's Pretty Page Picture Book. Fully **Illustrated.**
3 Pretty Pictures for Little Folks. Profusely **Illustrated.**
4 Child's Picture Story Book. With full-page **Illustrations.**
5 Little Tales for Little People. Full-page **Illustrations.**
6 Our Young Folks' Picture Book. Profusely **Illustrated.**

WARD, LOCK & CO., London, Melbourne, and New York.

COLOURED PICTURE BOOKS.

Price.

WARWICK HOUSE TOY BOOKS.

Great care has been taken to render these books worthy to be—what it is confidently hoped they will become—The Most Popular Children's Toy Books of the Day.

In handsome wrapper, *1s.* each; mounted on linen, *2s.*
*Those marked * cannot be supplied mounted.*

1/-

- *1 Domestic Animals.
- *2 Home & Field Animals.
- 9 Household Pets.
- 10 Picture Alphabet.
- 14 Country Scenes A B C.
- 16 Master Mousie's Supper Party.
- 18 Little Red-Riding Hood.
- 19 Little Alfred's Visit to Wombwell's Menagerie.
- 26 Mamma's New Picture Alphabet.
- 41 Nursery Rhymes A B C.
- 42 Cock Robin.
- 43 The Pussy-Cat's Hunting Party.
- 44 Pretty Pets and Happy Playmates.
- 46 The Babies' Alphabet and A B C of Animals.
- 47 A B C of Wonders, and Little Traveller's Alphabet.
- 48 The Royal Alphabet, and Little Shopkeeper's A B C.
- 49 Tottie's Favourite Nursery Rhymes.
- 50 Dick Whittington, and other Nursery Stories.
- 51 Doggie's Dinner Party, and Pussie's Tea Party.
- 52 Cinderella, and The Babes in the Wood.
- 53 John Gilpin, and The House that Jack Built.
- 54 Pussy-Cat Alphabet.
- 55 Punch & Judy Alphabet
- 56 Mamma's New Picture Scripture Alphabet (Old Testament).
- 57 Mamma's New Picture Scripture Alphabet (New Testament).
- 58 Jenny Wren Alphabet.
- 59 House that Jack Built.

THE PRETTY PRIZE PICTURE BOOKS.

With Coloured and other Illustrations, *1s.* each; cloth gilt, *1s. 6d.*

1/-

- 1 The Pretty Prize Picture Book of Easy Alphabets.
- 2 The Pretty Prize Picture Book of Nursery Tales.
- 3 The Pretty Prize Picture Book of Nursery Stories.

AUNT MARY'S INDESTRUCTIBLE BOOKS.

Imperial 16mo, picture wrappers, *6d.* Coloured Plates.

6*d.*

- 1 The Coloured Picture A B C Book.
- 2 Picture Alphabet Book.
- 3 Easy Words and Pretty Pictures.
- 4 Pretty Coloured Picture Book.
- 5 The Easy Reading Picture Book.
- 6 The Nursery Rhyme Book.
- 7 The Little Story Book.
- 8 Songs and Rhymes for the Little Ones.

WARD, LOCK & CO., London, Melbourne, and New York.

PICTURE BOOKS FOR CHILDREN.

Price

NEW SIXPENNY JUVENILE SERIES.

Fcap. 8vo, with **Illustrations**, cloth gilt, gilt edges, price *6d.* each.

6*d.*

1 **Glorious Footprints**; or, Britain's Great Men.
2 **Stirring Scenes in English History.**
3 **Trial and Triumph**: Children's Troubles and Joys.
4 **Little Susy's Six Servants.** By ELIZ. PRENTISS.
5 **Little Susy's Birthdays.** By same Author.
6 **Little Susy's Teachers.** By same Author.
7 **Original Poems.** By ANN and JANE TAYLOR.
8 **Poems for Children.** By A. & J. TAYLOR and Dr. WATTS.

AUNT FANNY'S SIXPENNY TOY BOOKS.

In Colours, 4to, coloured wrapper, price *6d.* each; on linen, *1s.* each.

6*d.*

5 **Alphabet of Animals.**
6 **Aunt Fanny's A B C.**
7 **Cock Robin.**
8 **Nursery Rhymes Alphabet.**
9 **Aunt Fanny's Nursery Rhymes.**
10 **Naughty Chickens.**
11 **Punch and Judy.**
12 **Old Mother Hubbard.**
13 **The Book of Animals.**
14 **Three Little Kittens.**
19 **Alphabet of Games.**
20 **Alphabet of Toys.**
21 **Poppy and Totty.**
23 **Cinderella.**
24 **The House that Jack Built.**
25 **John Gilpin.**
26 **Dick Whittington.**
27 **Doggie's Dinner Party.**
28 **Pussie's Tea Party.**
29 **The Babes in the Wood.**
30 **Nursery Stories.**
31 **Little Shopkeeper's Alphabet.**
32 **Little Traveller's Alphabet.**
33 **Tottie's Nursery Rhyme Book.**
34 **Famous Nursery Rhymes.**
35 **The Royal Alphabet.**
36 **The Babies' Alphabet.**
37 **The A B C of Animals.**
33 **The A B C of Wonders.**
39 **The House that Jack Built Alphabet.**

THREEPENNY INDESTRUCTIBLE BOOKS.

3*d.*

1 **Picture Alphabet.**
2 **Alphabet of Nursery Rhymes.**
3 **Nursery Rhymes.**
4 **Nursery Ditties.**
5 **The Dog's Dinner Party.**
6 **Three Little Kittens.**
7 **Babes in the Wood.**
8 **Red Riding Hood.**
9 **Cinderella**; or, the Little Glass Slipper.
10 **Cock Robin.**
11 **Old Mother Hubbard.**
12 **Punch and Judy.**

Superbly printed in Colours, fcap. 8vo, Mounted on cloth, each *3d.*

WARD, LOCK & CO., London, Melbourne, and New York.

CHEAP TOY BOOKS FOR CHILDREN.

Price

THE NATIONAL NURSERY TALES.

With Coloured Pictures. Stitched in wrapper, price *2d.* each.

2*d.*

1 Little Red Riding Hood.
2 Puss in Boots.
3 Jack and the Beanstalk.
4 Cinderella.
5 Jack, the Giant Killer.
6 Goody Two Shoes.
7 The Three Bears.
8 Tom Thumb.

WARD AND LOCK'S

PENNY PICTURE FIRST BOOKS.

Profusely Illustrated, and stitched in attractive coloured wrapper, price *1d.* each.

1*d.*

1 The Easy A B C.
2 Easy Words.
3 Easy Spelling.
4 Easy Reading.

GRACIE GOODCHILD'S PRETTY PICTURE BOOKS.

Beautifully **printed in Colours,** demy 8vo, coloured wrapper, price *3d.* each.

3*d.*

1 Pretty Picture Alphabet.
2 Pretty Picture A B C.
3 Pretty Picture Primer.
4 Pretty Picture Nursery Rhymes.

AUNT AFFABLE'S PRETTY PLAY BOOKS.

Royal 8vo, coloured wrappers, plain, price *2d.* each; **coloured,** *3d.* each.

2*d.*

1 The A B C Book.
2 A B C of Objects.
3 Death and Burial of Cock Robin.
4 Child's Picture Book of Animals.

THE CHILD'S PICTURE BIBLE STORIES.

Royal 8vo, coloured wrapper, plain, price *2d.* each; **coloured** *3d.* each.

2*d.*

1 Life and Teachings of our Lord Jesus Christ.
2 From the Creation to the Deluge.
3 The History of Abraham, Isaac, and Jacob.
4 The Story of the Mighty Men of Israel.
5 The History of David.
6 The Apostles and our Saviour's Teaching.

PENNY COLOURED TOY BOOKS.

Beautifully **printed in Colours.** In Packets, containing 12 Books, *1s.* each.

1/-

1 A Picture Alphabet.
2 Alphabet of Nursery Rhymes
3 Nursery Rhymes.
4 Nursery Ditties.
5 The Dog's Dinner Party.
6 Three Little Kittens.
7 Babes in the Wood.
8 Red Riding Hood.
9 Cinderella.
10 Cock Robin.
11 Old Mother Hubbard.
12 Punch and Judy.

BEETON'S PENNY CHILDREN'S BOOKS.

Price *1d.* each; the Series of Six, post free for *8d.*

1*d.*

1 Beeton's Pictorial A B C.
2 Beeton's Pictorial Speller.
3 Beeton's Pictorial Primer.
4 Beeton's Pictorial Reader.
5 Beeton's Pictorial History of England.
6 Beeton's Pictorial Bible History.

WARD, LOCK & CO., London, Melbourne, and New York.

Spelman
392 Waverly Avenue